Forward Scatter Meteor Radar: the Science Behind the Pings

HamSCI Workshop
March 2026

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and

Von Braun Astronomical Society

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HamSCI Meteor Scatter QSO Party

Work the rocks! Decode the pings!

Aug 11-12 and Dec 12-13, 2025

- Contribute to science as we strive to uncover the secrets of meteor scatter (MS) propagation
- Join hundreds of operators on 6 m (50.260 MHz) and 10 m (28.145 MHz) MSK144 during the August Perseid and December Geminid meteor showers
- **Two-Way** (transmit/receive) and **Monitor** (receive only) stations are needed
- Sending reception reports to PSKReporter is important to the success of these events. See the Software Setup section for details
- Enter the MSQP Competition - Who makes the most QSOs or generates the most reception reports? See the MSQP Operating Guidelines and Rules and **KO4GLN's poster** describing the event.

Outline

Where do meteors come from and what are their characteristics?

When are meteors visible (audible) and why?

Which frequencies are best to use?

What are the different types of meteor scatter signals?

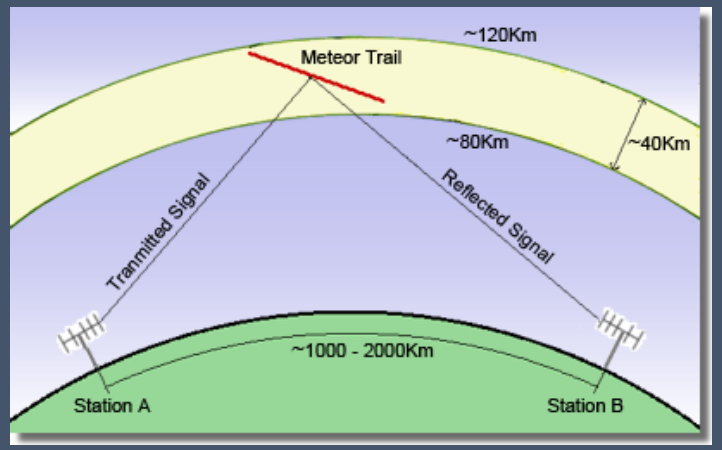
Examples of MSK144 signals

What can we learn about meteor scattering physics from MSQP data?

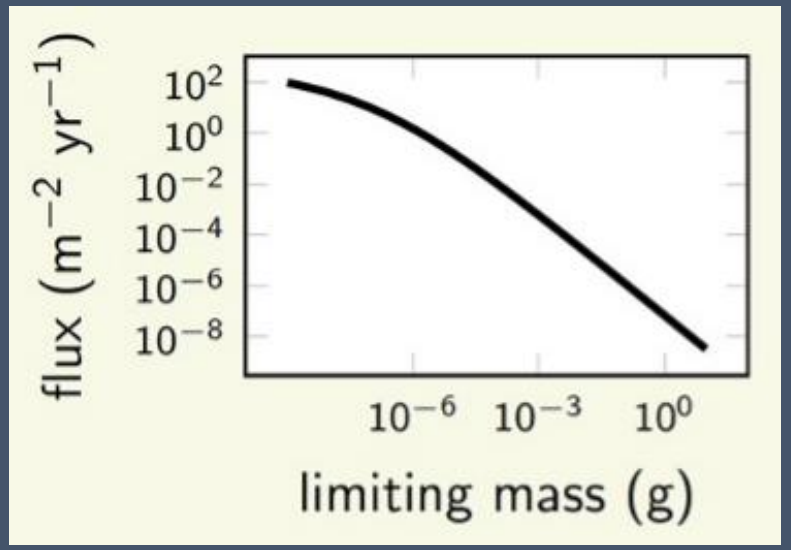
What are some tools for predicting and monitoring meteor activity?

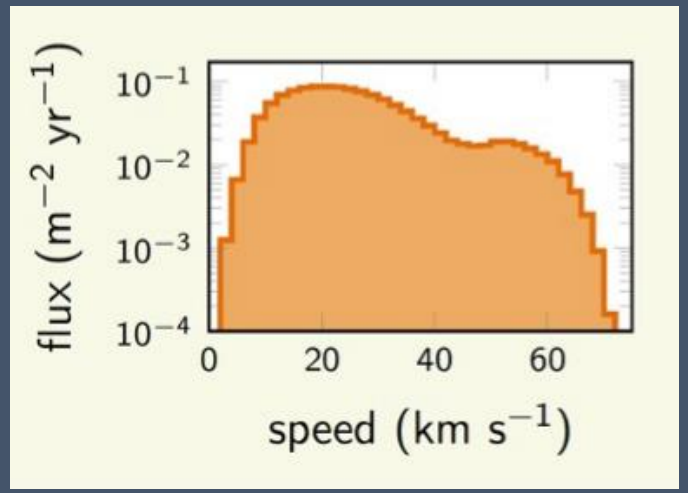
Meteors provide the free electrons to scatter a radio signal

As the meteoroid enters the atmosphere at high speed (10 – 70 km/s) it ionizes the oxygen and nitrogen molecules generating ions and free electrons which scatter the RF over the horizon (also makes light)



https://www.areg.org.au/archives/210418





NASA MEO/A. Moorhead

SOME TERMINOLOGY

Meteoroids – bits in space

- Consist of small pieces (grain of sand, particle of dust) of mostly cometary (90%) or asteroidal (10%) material
- **Shower** meteoroids associated with comet and asteroid orbits
- **Sporadic** meteoroids associated mostly with comet families

Meteors – bits burning up in the atmosphere

- Visible light from a meteor comes mostly from the ionization of the atmosphere

Meteorites – hit the ground

Suggs NN4NT

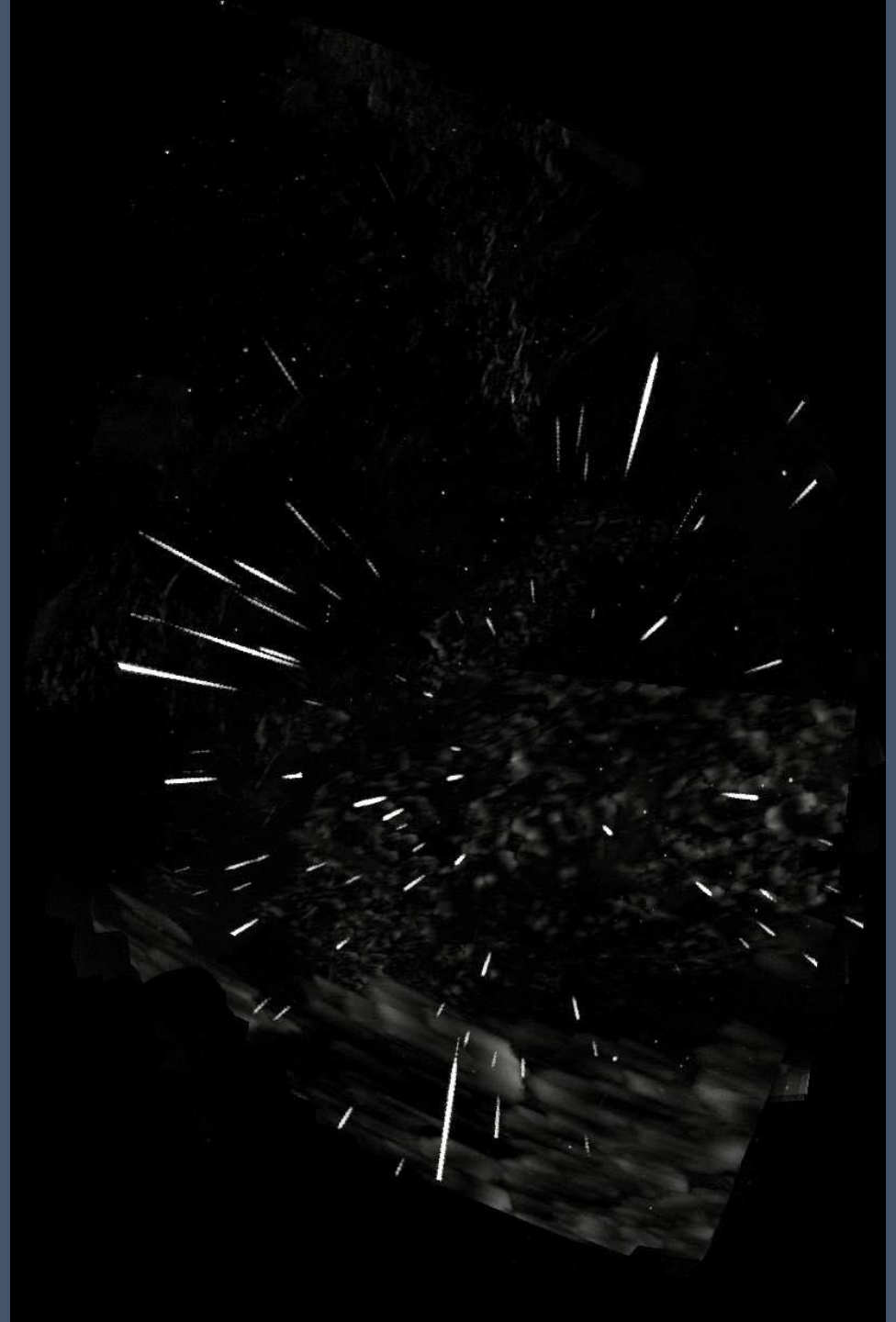
http://cdn.sci-news.com/images/2019/05/image_57220-Atacama-Desert-Meteorite.jpg

Perseids 2025

From Global Meteor Network camera at NASA MSFC's Automated Lunar and Meteor Observatory (ALAMO)

79 meteors in 3 nights

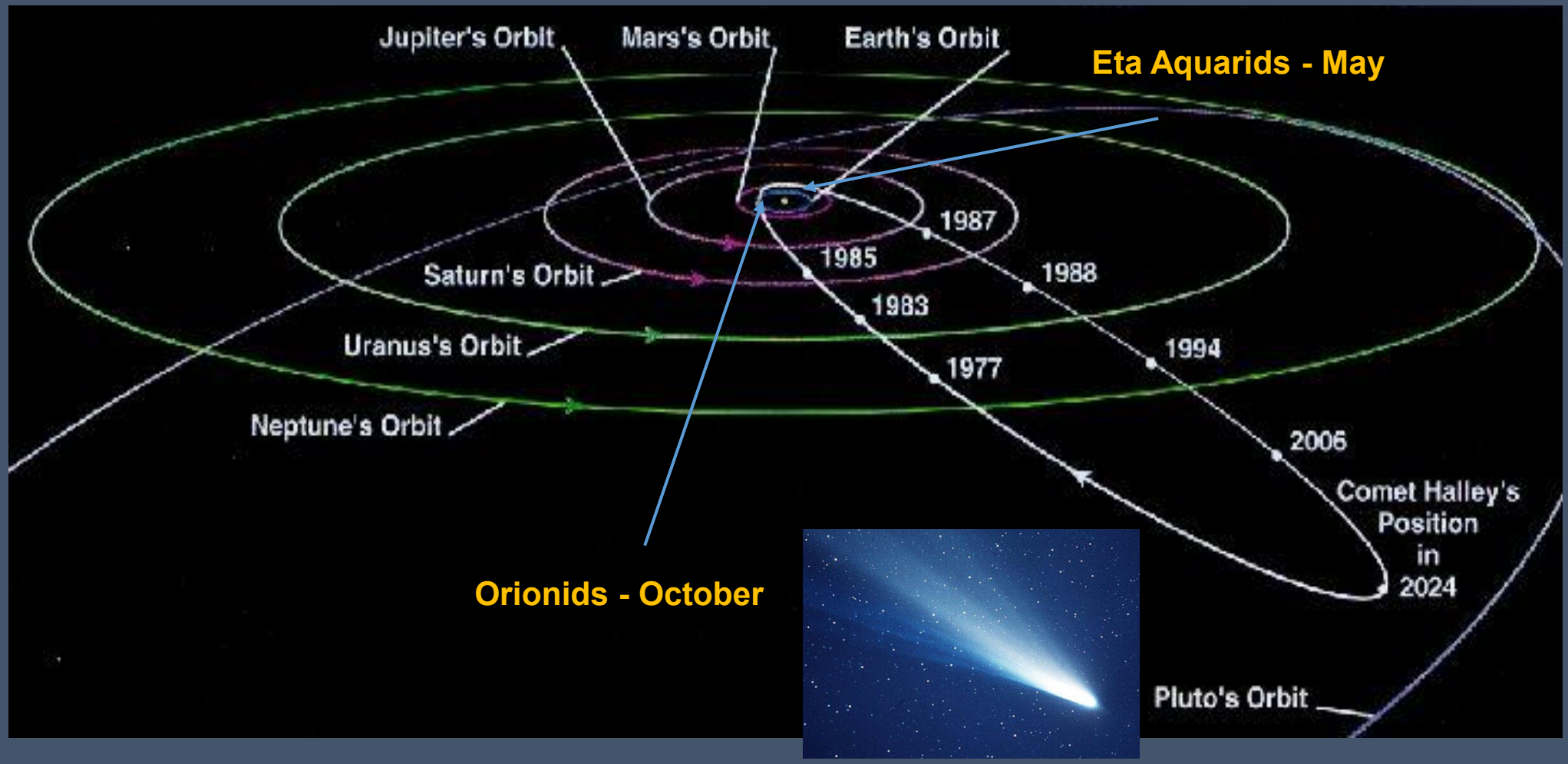
Image from Bill Cooke/NASA Meteoroid Environment Office



Leonid video and forward scatter audio

Intensified video camera, Leonids 1999 from southern New Mexico. Audio from receiver tuned to distant analog TV video carrier.

Comet Halley particles are responsible for 2 meteor showers every year



https://www.meteorshowers.org/

Meteors are more prevalent in the morning and during meteor showers

Diurnal variation – like bugs on a windshield

- Car (Earth) going 30 km/s around the sun
- Bugs (meteoroids) going up to 40 km/s around the sun, some head-on
- Impact speed is vector sum of these – many hit windshield, only really fast ones hit rear window

There are fewer sporadic meteors in the spring, +/- 20% annual variation

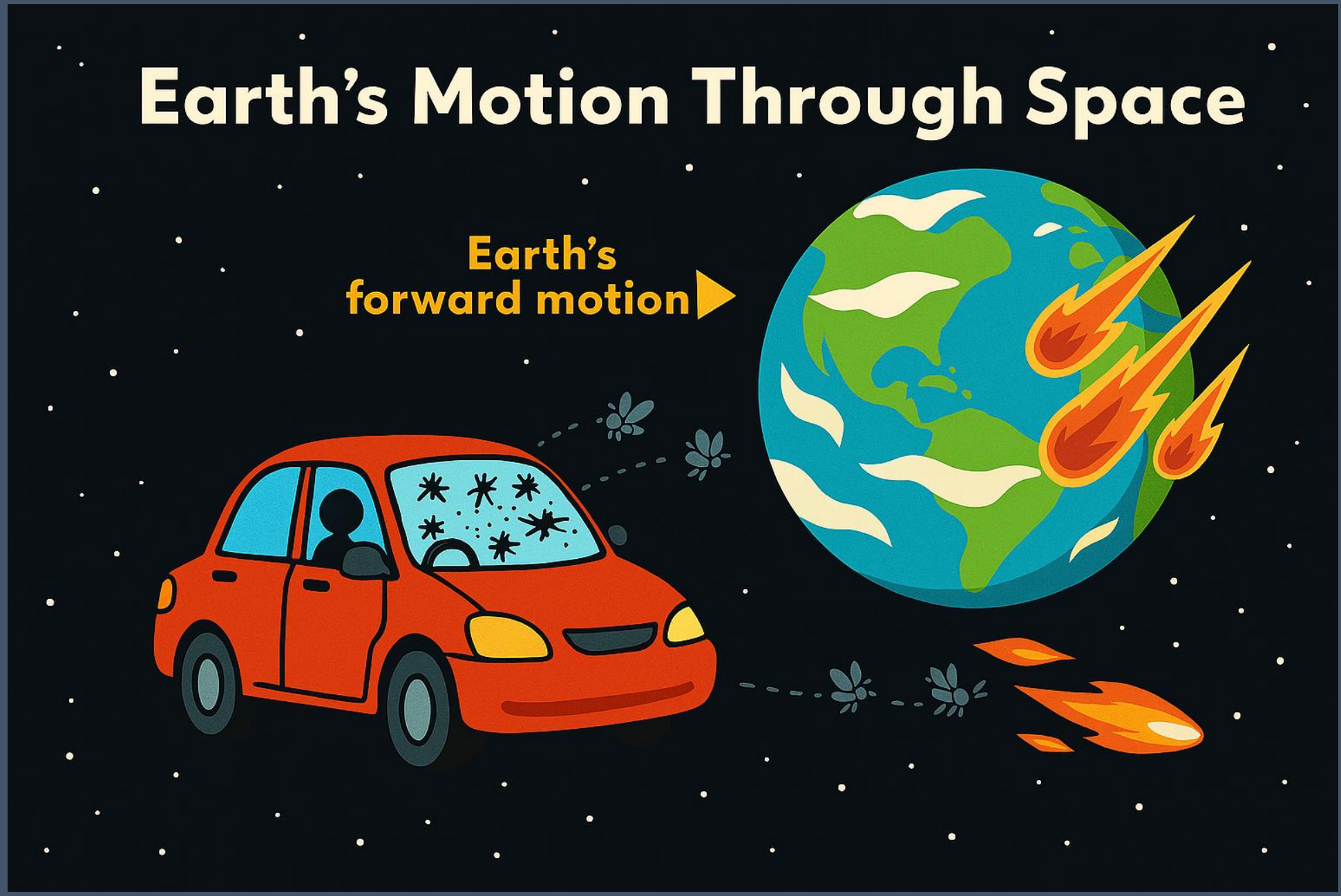
Sporadic meteors are there all the time from all over the sky (sort-of)

During meteor showers…

There are relatively more large meteors

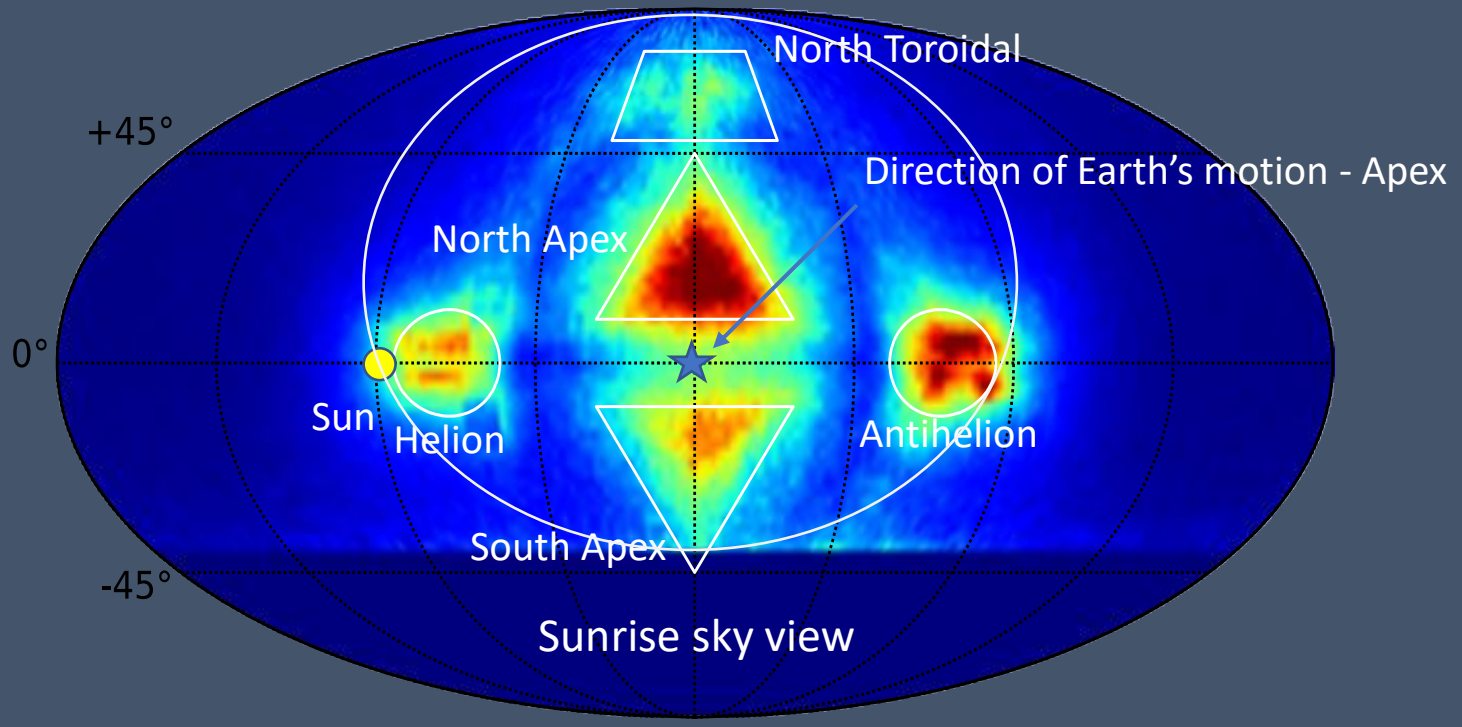
They all come from a common point called the radiant

Name	Peak Date	Approx. Meteors/hr	Speed
Quadrantids	Jan. 3	120	43 km/s
Eta Aquariids	May 6	60	66
Arietids	Jun. 9 (daytime)	45	41
Perseids	Aug. 11-13	90	60
Orionids	Oct. 20-23	20	67
Geminids	Dec. 12-13	120	36



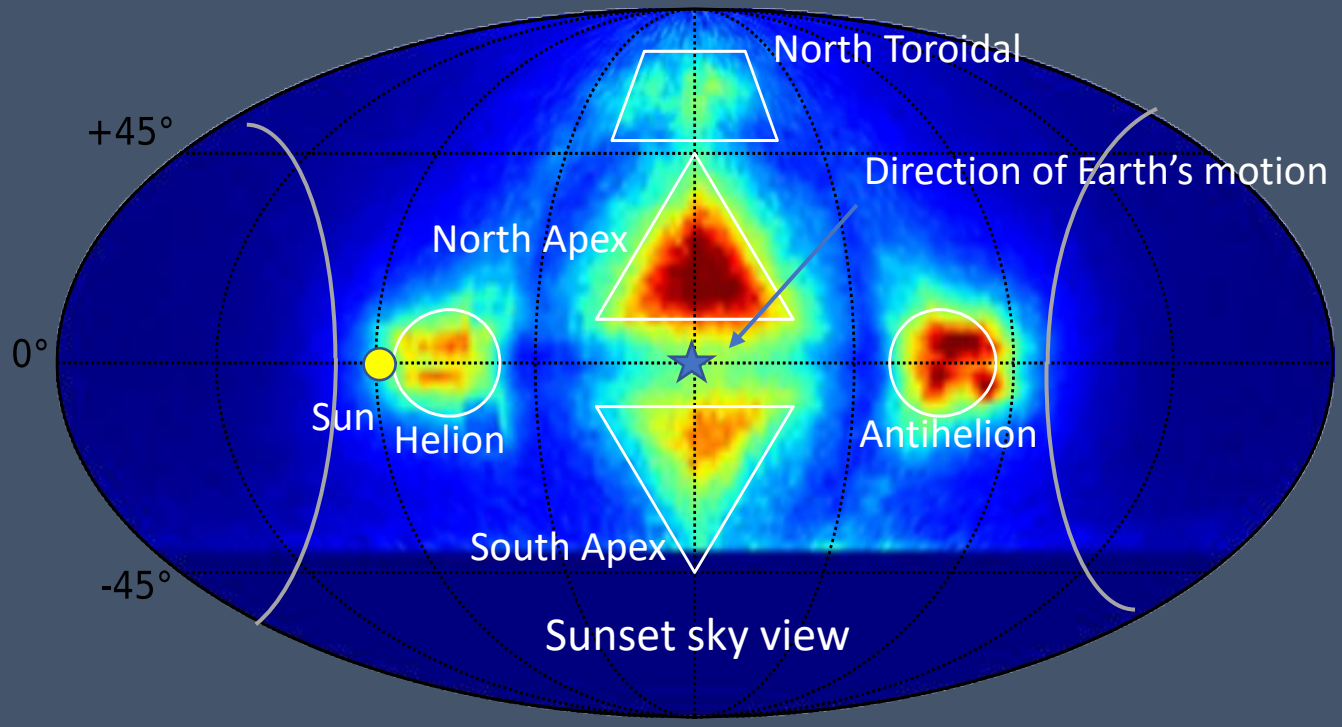
Generated by CoPilot AI

Sporadic sources are not isotropic



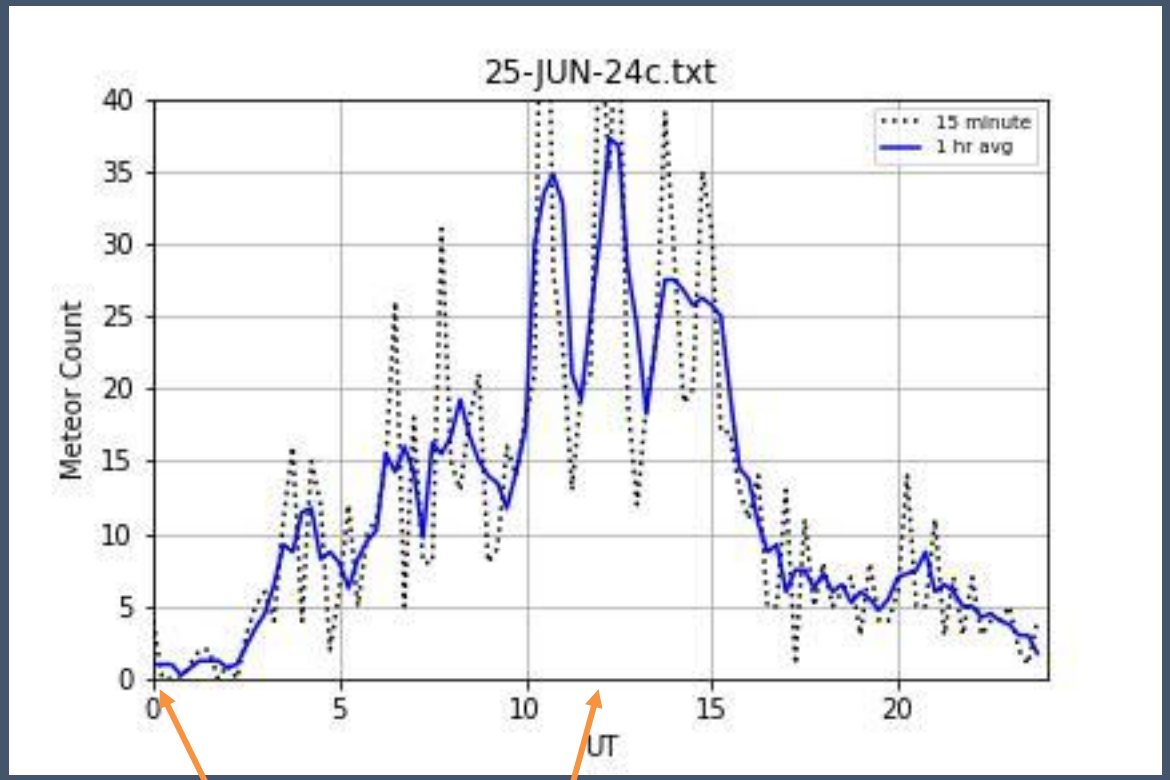
Meteoroid Flux as a function of direction as observed by Canadian Meteor Orbit Radar. Observational biases have been taken into account and results have been weighted by a constant limiting kinetic energy. Coordinate system is Earth-centered ecliptic.

Sporadic sources are not isotropic



Meteoroid Flux as a function of direction as observed by Canadian Meteor Orbit Radar. Observational biases have been taken into account and results have been weighted by a constant limiting kinetic energy. Coordinate system is Earth-centered ecliptic.

Digital TV pilot tone counts show diurnal variation



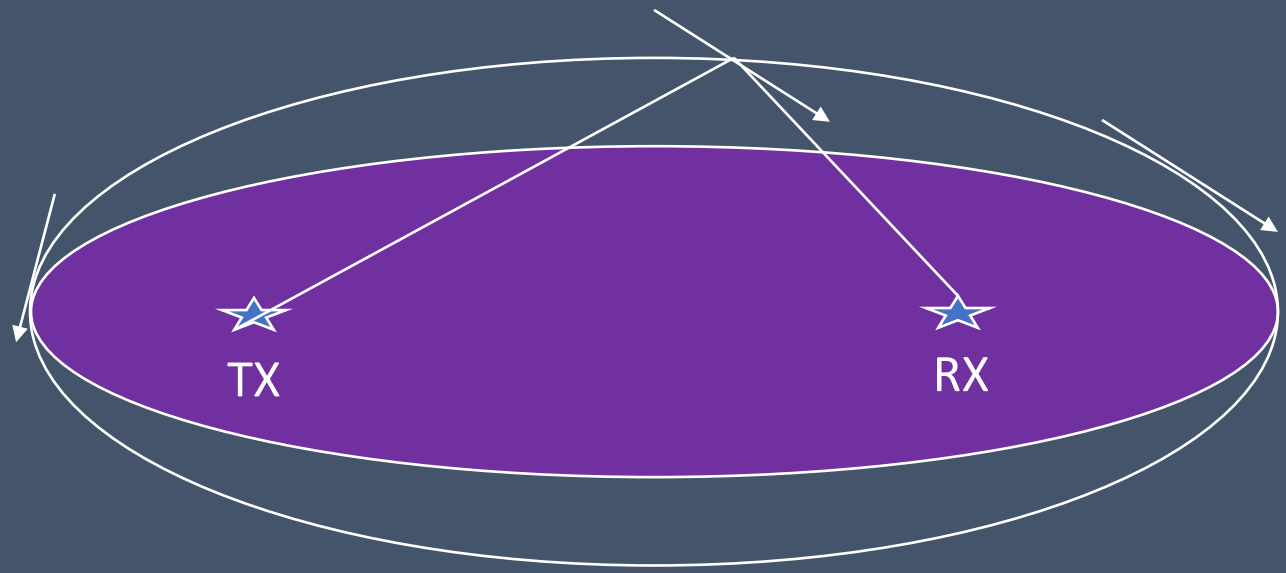
Sunset

Sunrise

From MSFC ARC NN4SA
DTV channel 3, 60.3085 USB
Several transmitters in range
Icom R8500
Dipole at 6ft
Suggs count software

For maximum signal the meteor must lie tangent to an ellipsoid with the transmitter and receiver at the foci

- This geometry favors certain path directions as the shower radiant moves across the sky
- The vast majority of meteors don’t satisfy this ”specular” condition and can’t be “heard”
- Overdense trails “crinkle” with time and don’t have to satisfy this constraint



Return Power is a strong function of wavelength

Important point is that the signal strength goes as the cube of the wavelength, λ, and the square of the electron line density, q

$$P_R = \frac{P_T G_T G_R \lambda^3 \sigma_e}{64\pi^3} \frac{q^2 \sin^2 \gamma}{(R_1 R_2)(R_1 + R_2)(1 - \sin^2 \phi \cos^2 \beta)}$$

$$= 5 \times 10^{-32} \frac{P_T G_T G_R \lambda^3 q^2 \sin^2 \gamma}{(R_1 R_2)(R_1 + R_2)(1 - \sin^2 \phi \cos^2 \beta)} \quad \text{watts}$$

You want to use the longest wavelength (lowest frequency) possible. If you get into HF bands, Ionospheric effects can dominate so lower VHF (40 – 100 MHz) is best. From McKinley, 1961 eq. 9-3.
So 10m should be preferable to 6m.

Forward Scatter Geometry

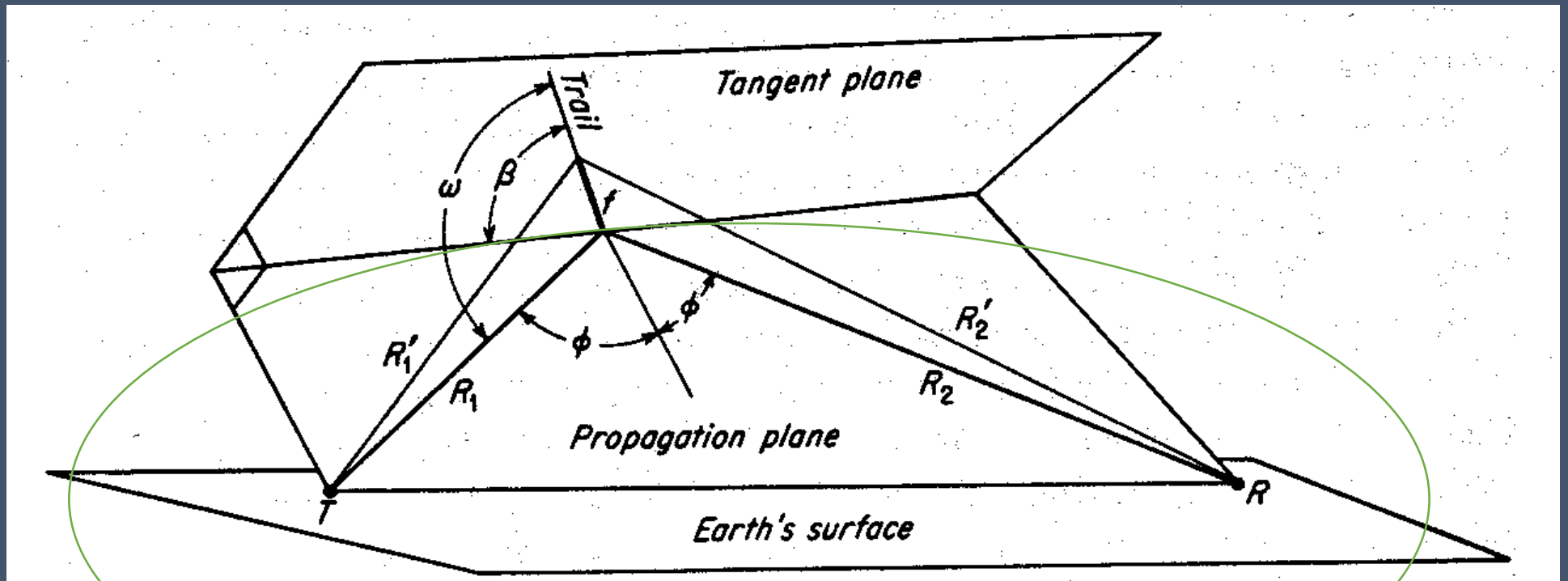


FIG. 9-1. The geometry of forward-scatter involved in the calculation of f, the length of one-half of the first Fresnel zone.

From "Meteor Science and Engineering", D.W.R. McKinley

Signal duration is proportional to square of the wavelength

$$T_{un} = \frac{\lambda^2 \sec^2 \phi}{16\pi^2 D}$$

D is the electron diffusion coefficient in m^2/sec

From “Meteor Science and Engineering”, D.W.R. McKinley

Dependence of strength and duration for various amateur MSK144 frequencies

Frequency MHz	Rel strength	Rel Str dB	Rel duration
144.15	0.04	-13.7	0.12
50.26	1.00	0.0	1.00
28.145	5.69	7.6	3.19

Scattered power is proportional to the wavelength^3 or 1/frequency^3

Signal duration is proportional to wavelength^2

Two Types of Meteor Trails

Underdense

- Weak echoes
- Short-lived (<1 second)
- Electron density is so low that individual electrons don't interact with each other)
- Scattering geometry must be specular

Overdense

- Strong echoes
- Long-lived (many seconds)
- Electrons act in concert like a metal tube
- Scattering geometry should be specular but upper atmospheric winds can "crinkle the tube"

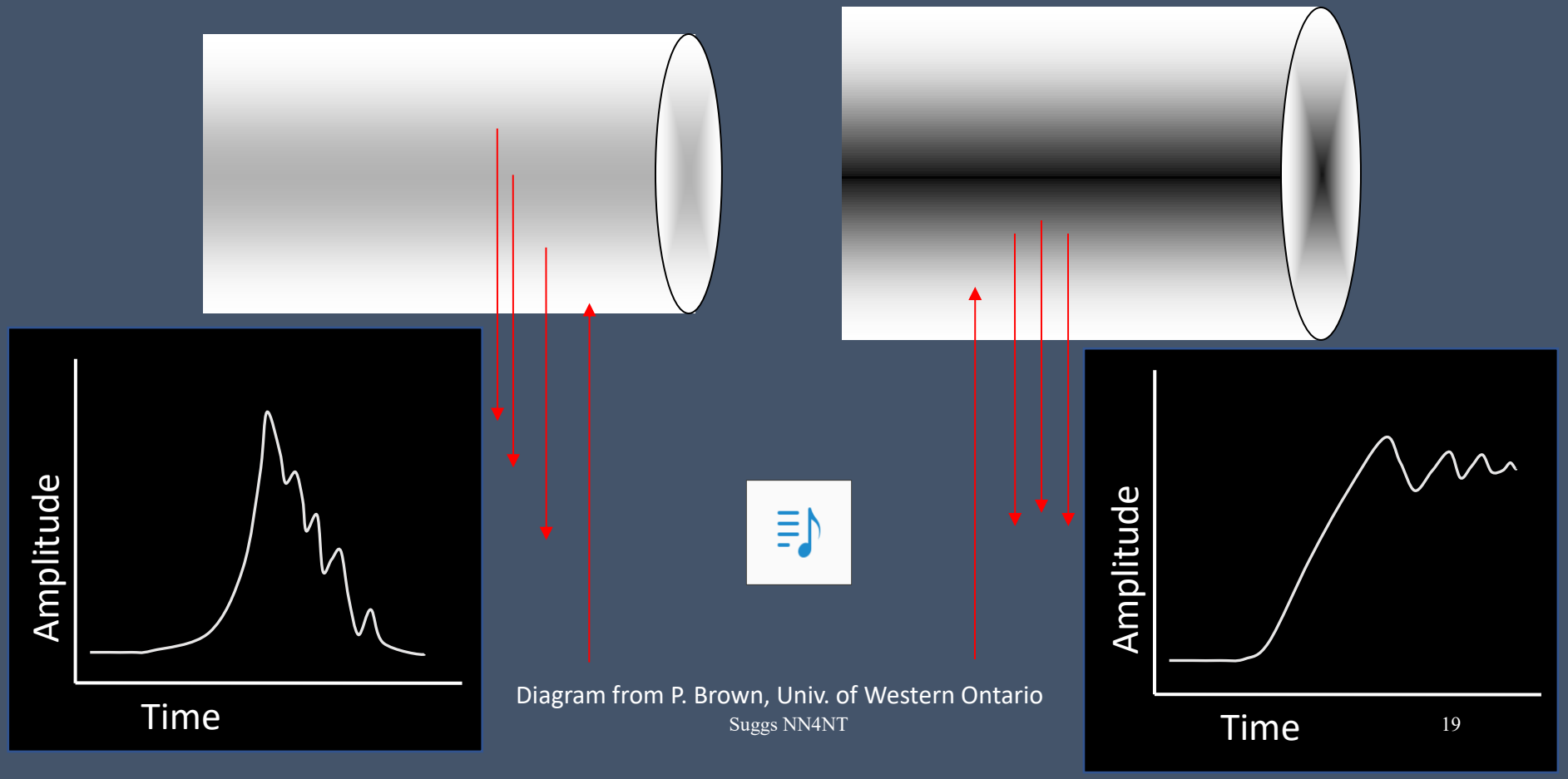
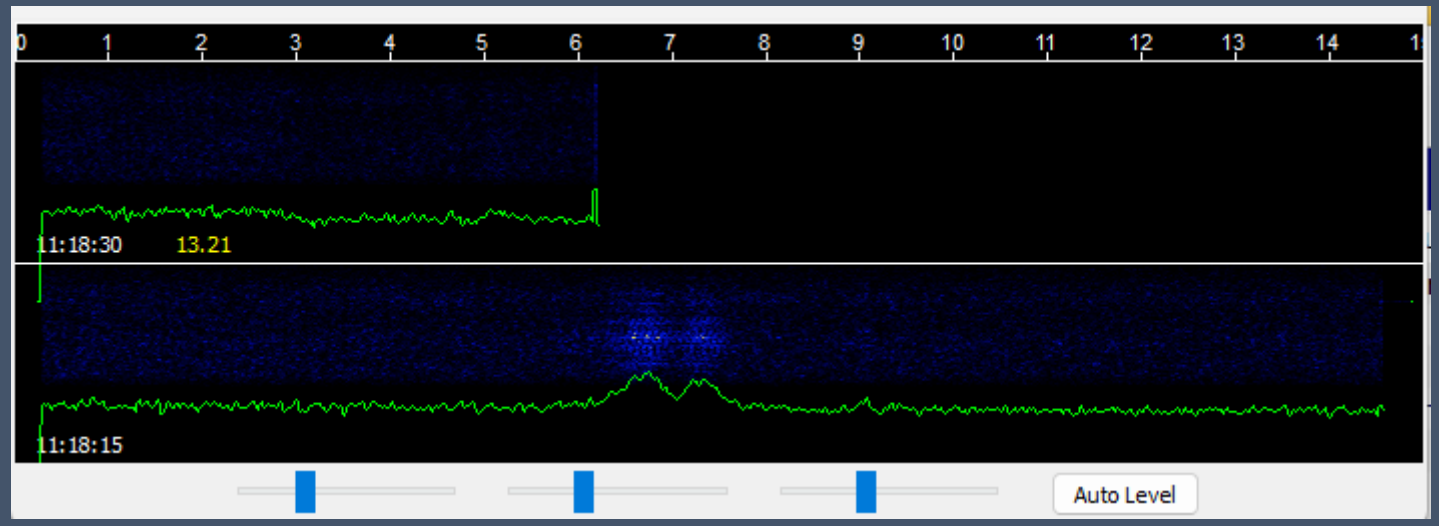


Diagram from P. Brown, Univ. of Western Ontario

QSO sample – KK0U and NN4NT 2025 Perseids on 10m



Band Activity

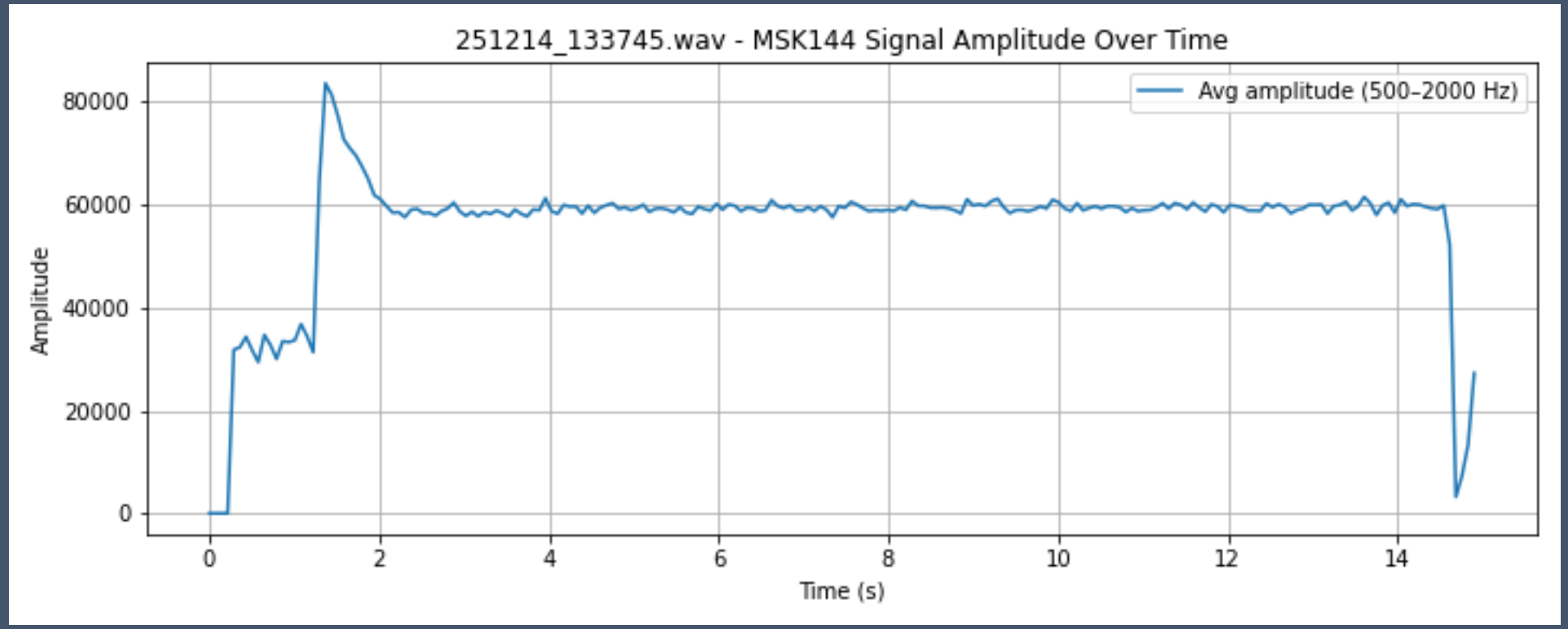
UTC	dB	T	Freq	Message
110915	-2	13.7	1504	& NN4NT KK0U EM48 MO-IL
110915	-1	14.2	1505	& NN4NT KK0U EM48 MO-IL
110915	0	14.2	1505	& NN4NT KK0U EM48 MO-IL
------ 2025-07-29 - 11:13:15 UTC - 10m - MSK144 ------				
111315	-2	1.1	1508	& NN4NT KK0U R+04
------ 2025-07-29 - 11:18:15 UTC - 10m - MSK144 ------				
111815	1	6.5	1511	& NN4NT KK0U 73
111815	5	6.8	1511	& NN4NT KK0U 73

Tx Messages

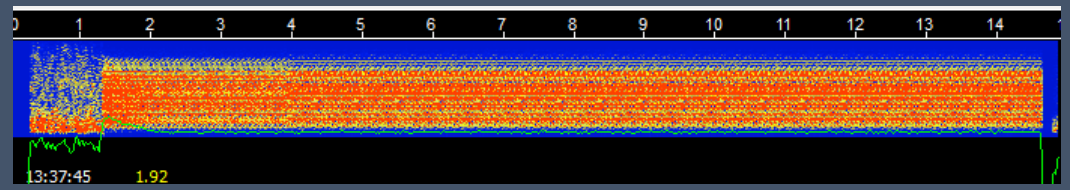
UTC	dB	T	Freq	Message
------------------ 10m -----------------				
110915	-2	13.7	1504	& NN4NT KK0U EM48 MO-IL
110930	Tx		1500	& KK0U NN4NT -02
111000	Tx		1500	& KK0U NN4NT -02
111030	Tx		1500	& KK0U NN4NT -02
111100	Tx		1500	& KK0U NN4NT -02
111130	Tx		1500	& KK0U NN4NT -02
111200	Tx		1500	& KK0U NN4NT -02
111230	Tx		1500	& KK0U NN4NT -02
111300	Tx		1500	& KK0U NN4NT -02
111315	-2	1.1	1508	& NN4NT KK0U R+04
111330	Tx		1500	& KK0U NN4NT RR73
111603	Tx		1500	& CQ NN4NT EM64
111630	Tx		1500	& KK0U NN4NT RR73
111700	Tx		1500	& KK0U NN4NT RR73
111730	Tx		1500	& KK0U NN4NT RR73
111800	Tx		1500	& KK0U NN4NT RR73
111815	1	6.5	1511	& NN4NT KK0U 73

Local station from NN4SA

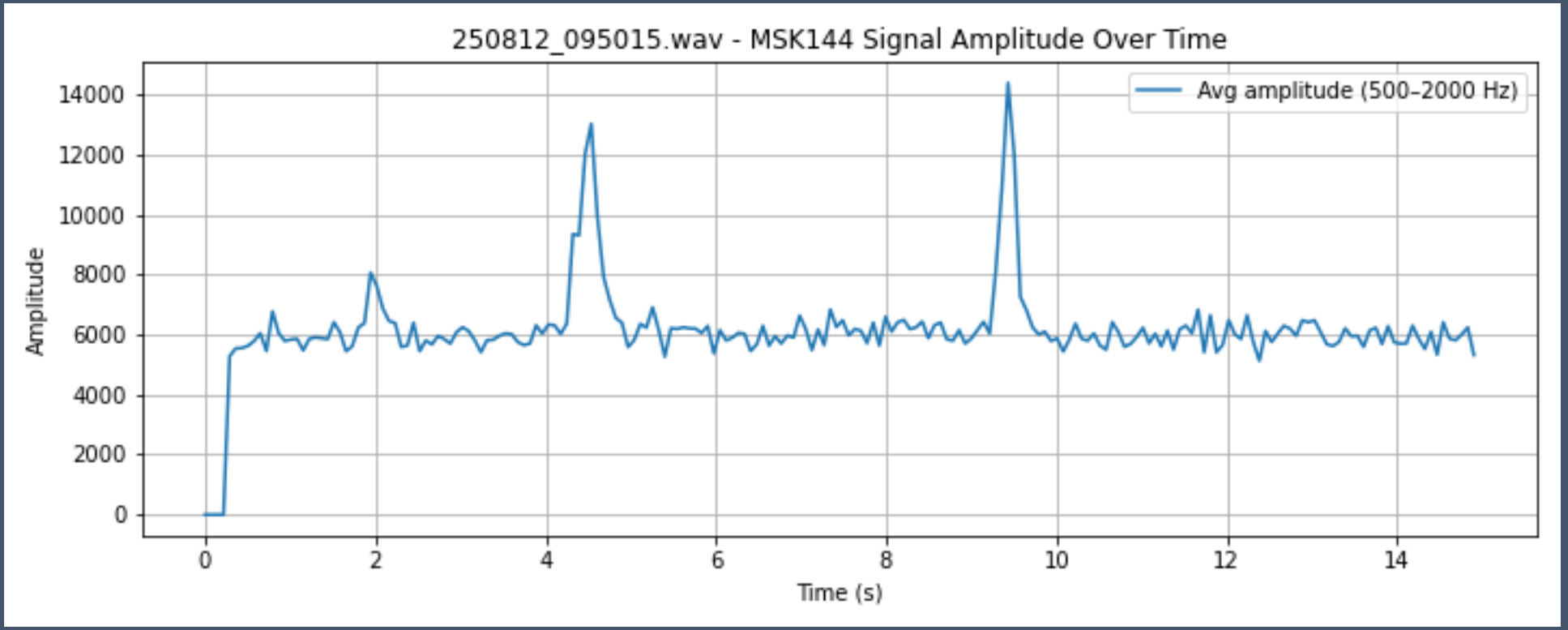
MSK144
2000 baud MSK, 2.5 kHz BW
72 msec 128 bit messages, 144 bit packets
Typically 15 sec T/R cycles,
approximately 208 packets/cycle



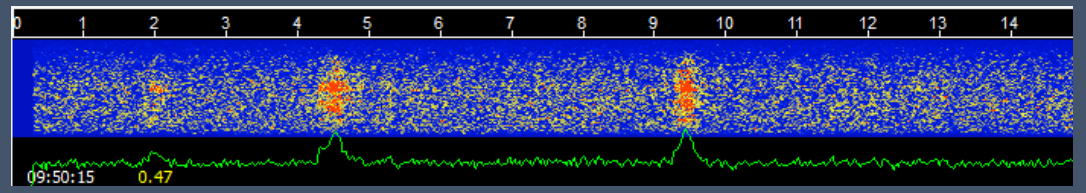
KQ5U KY4G EM64
KQ5U KY4G R-01



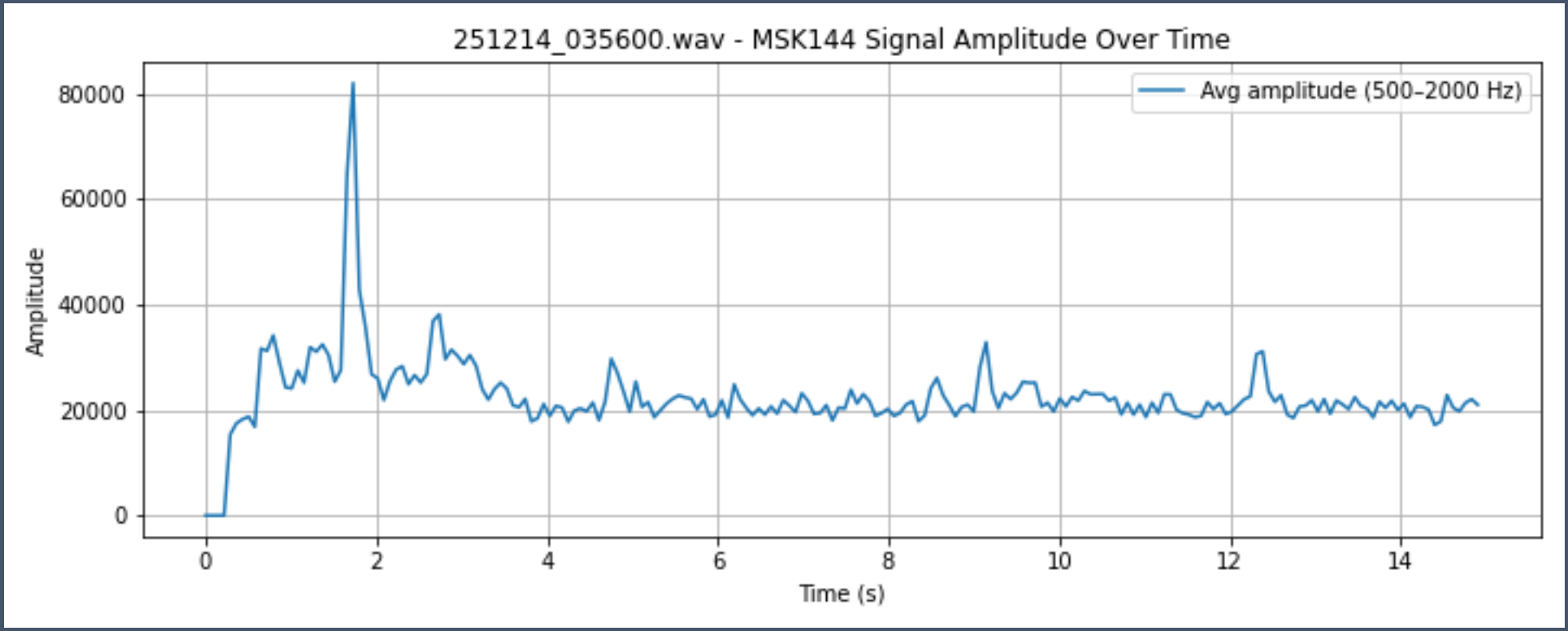
Pair of 10m underdense meteors during Perseids



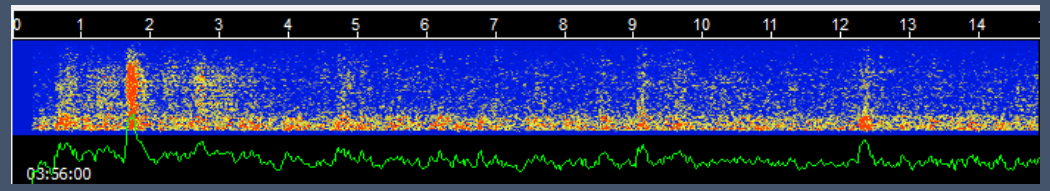
CQ K1HTV FM18
CQ K1HTV FM18
West of DC
38.651988, -77.953917



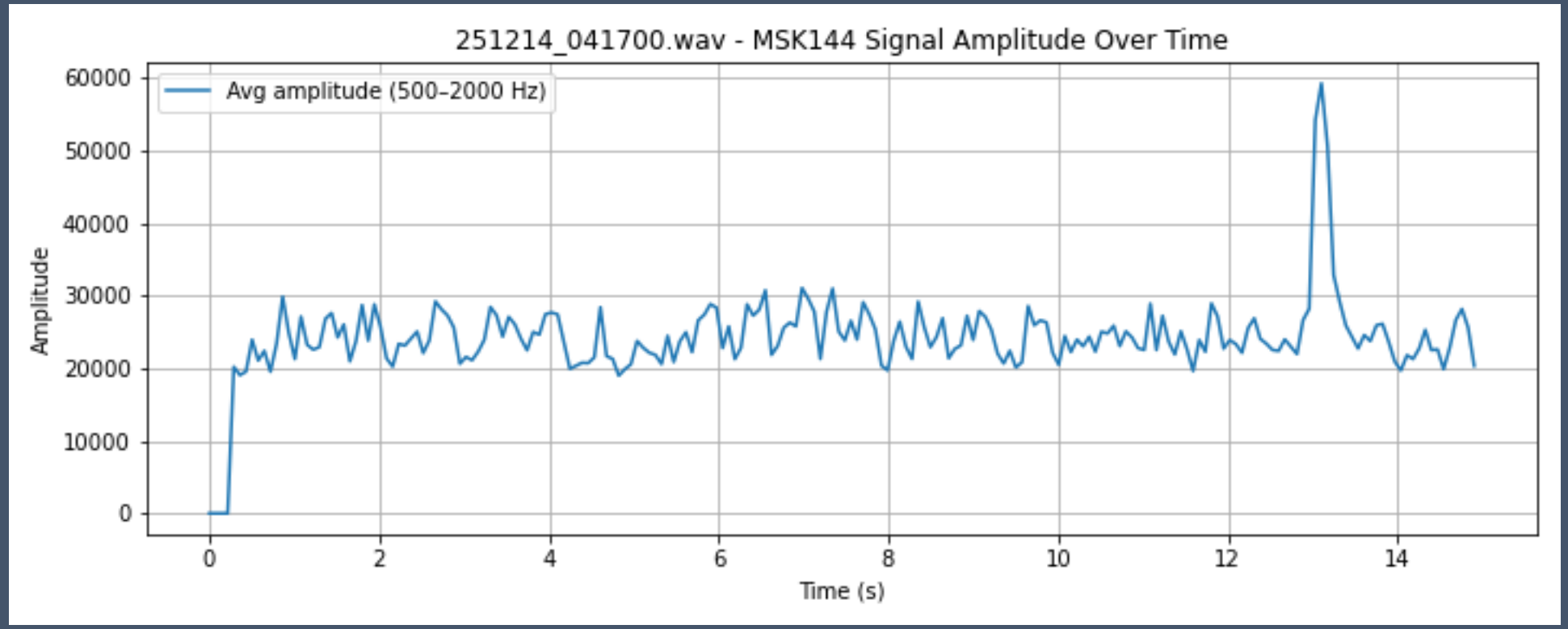
Underdense 6m meteor during Geminids



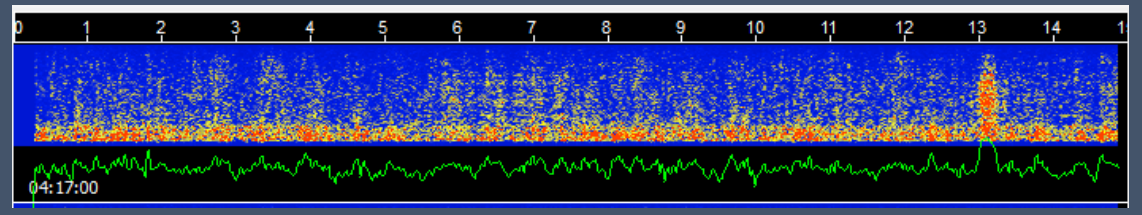
K5HPT W8DPK 73
EM89 near Columbus OH
39.870848, -83.267503



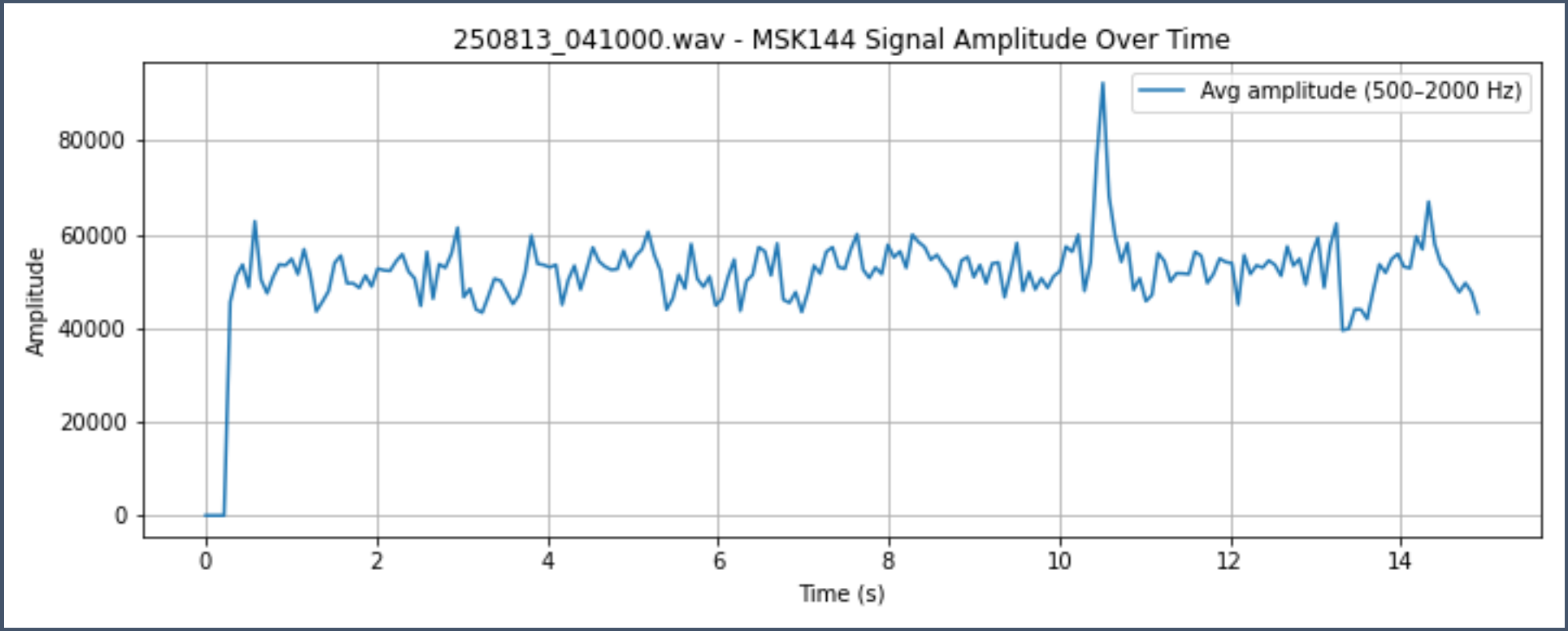
Another 6m underdense meteor during Geminids 2025



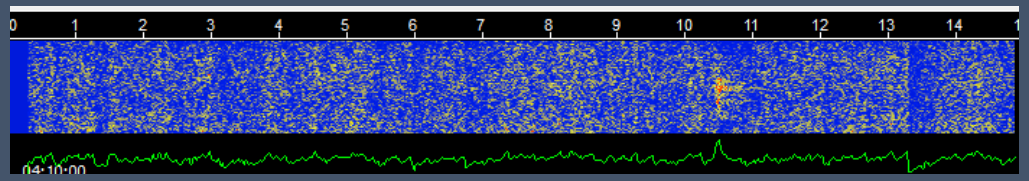
K5HPT NO3I EN90
Newcastle PA
40.989418, -80.336151



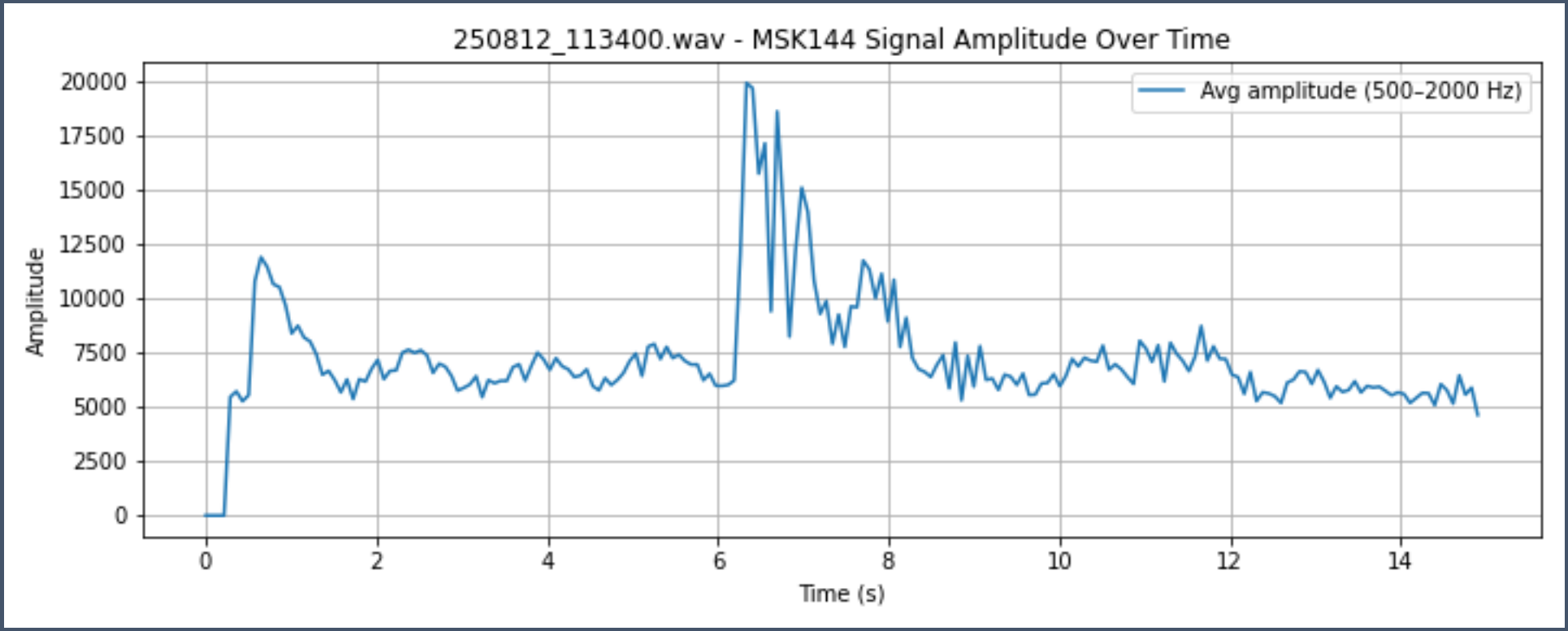
Underdense meteor on 2m during Perseids



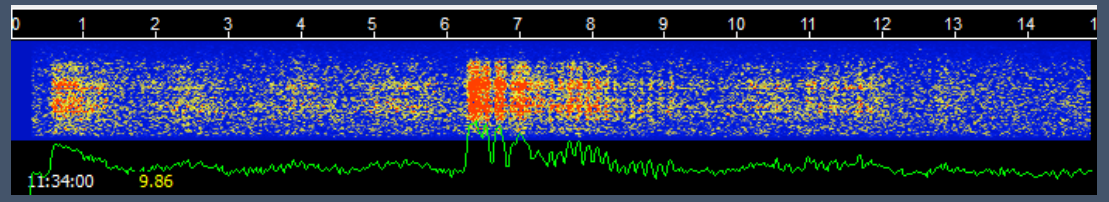
CQ AB5CC EM14 (2x)
South OK
34.054182, -96.387515



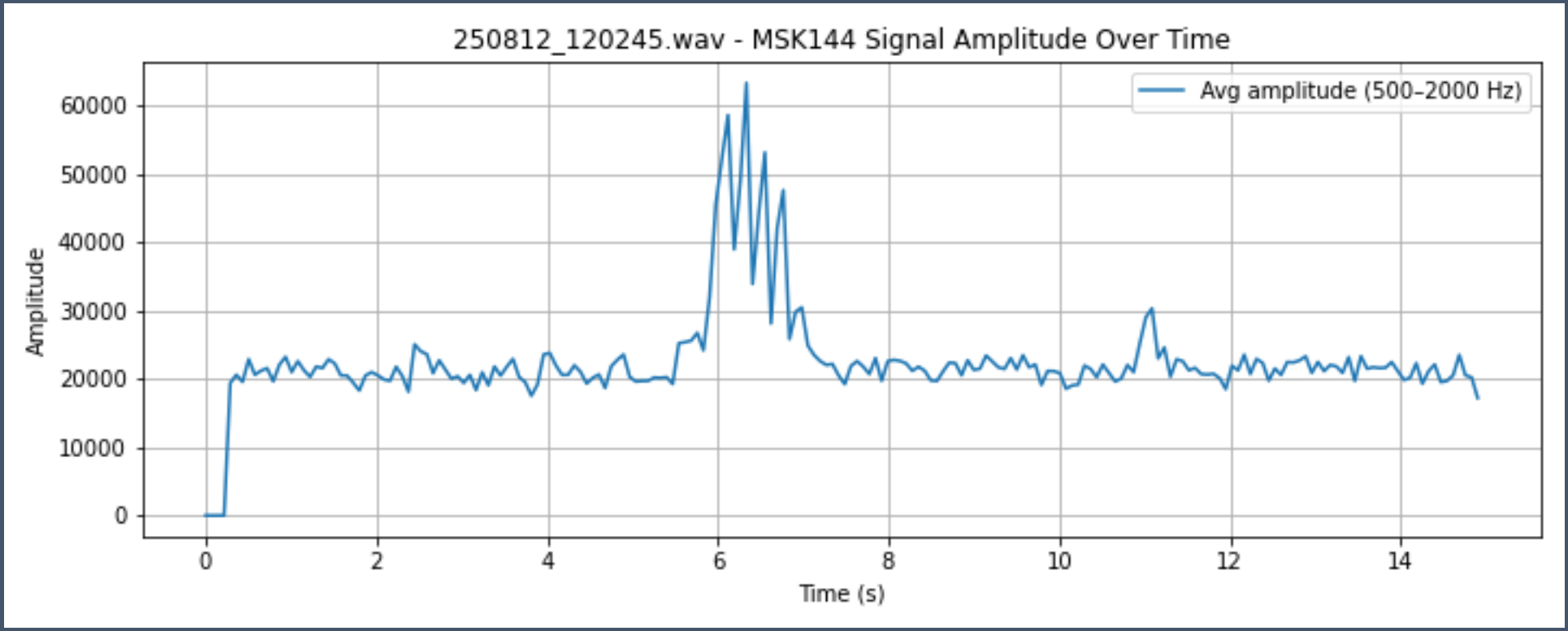
Likely overdense meteor on 10m during Perseids



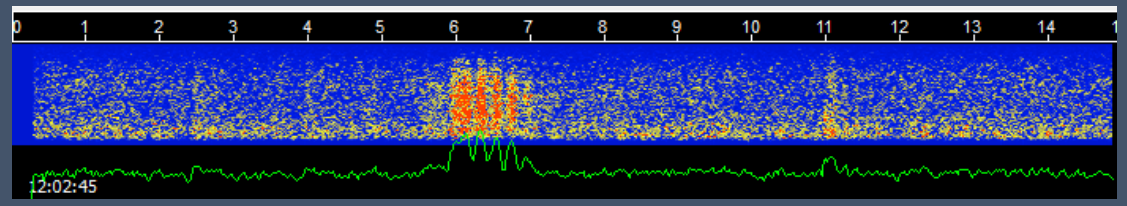
W2JC K2DRH -02 (3X)
West of Chicago
41.742381, -90.220016

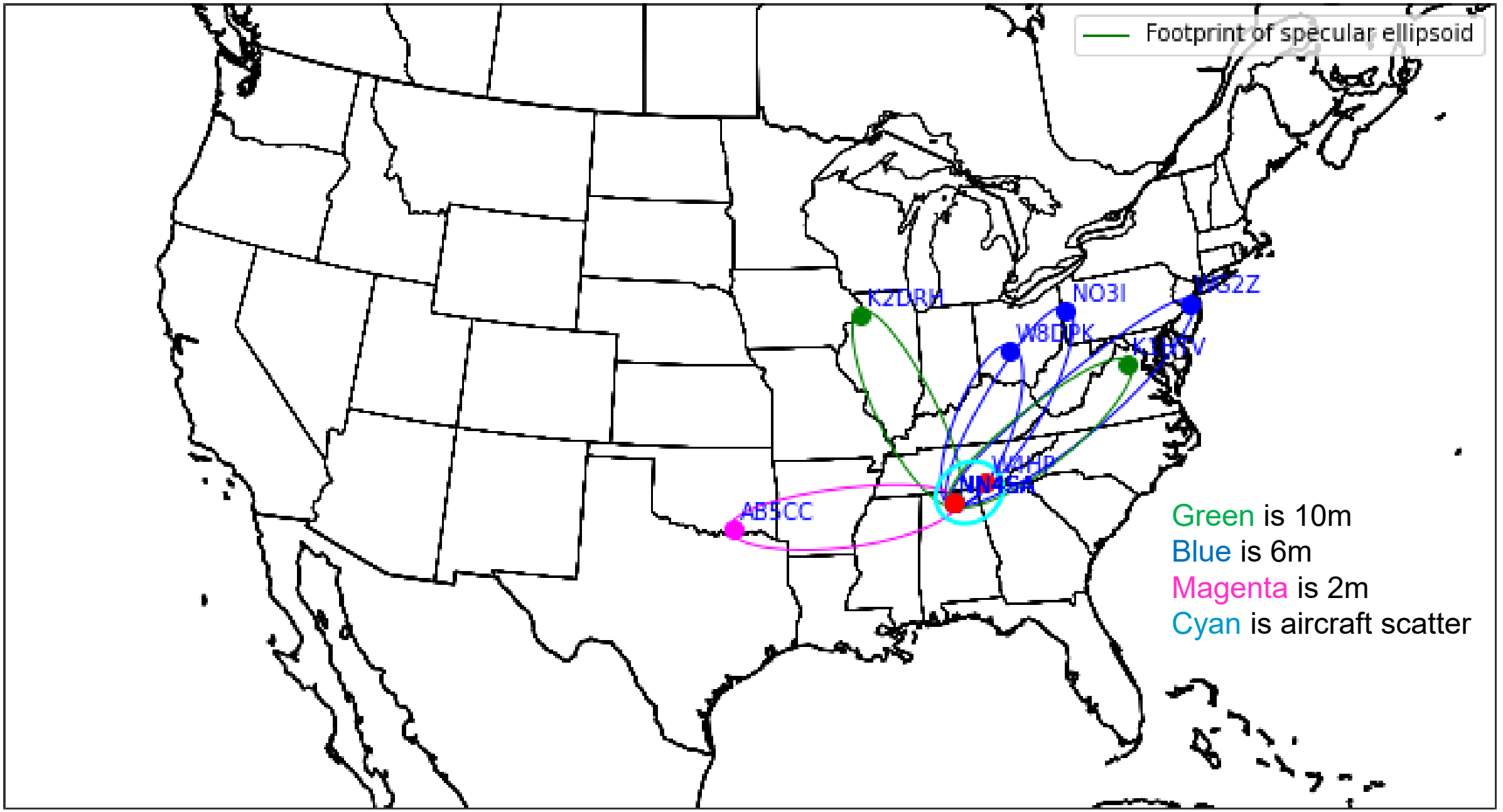


Possible overdense on 6m during Perseids

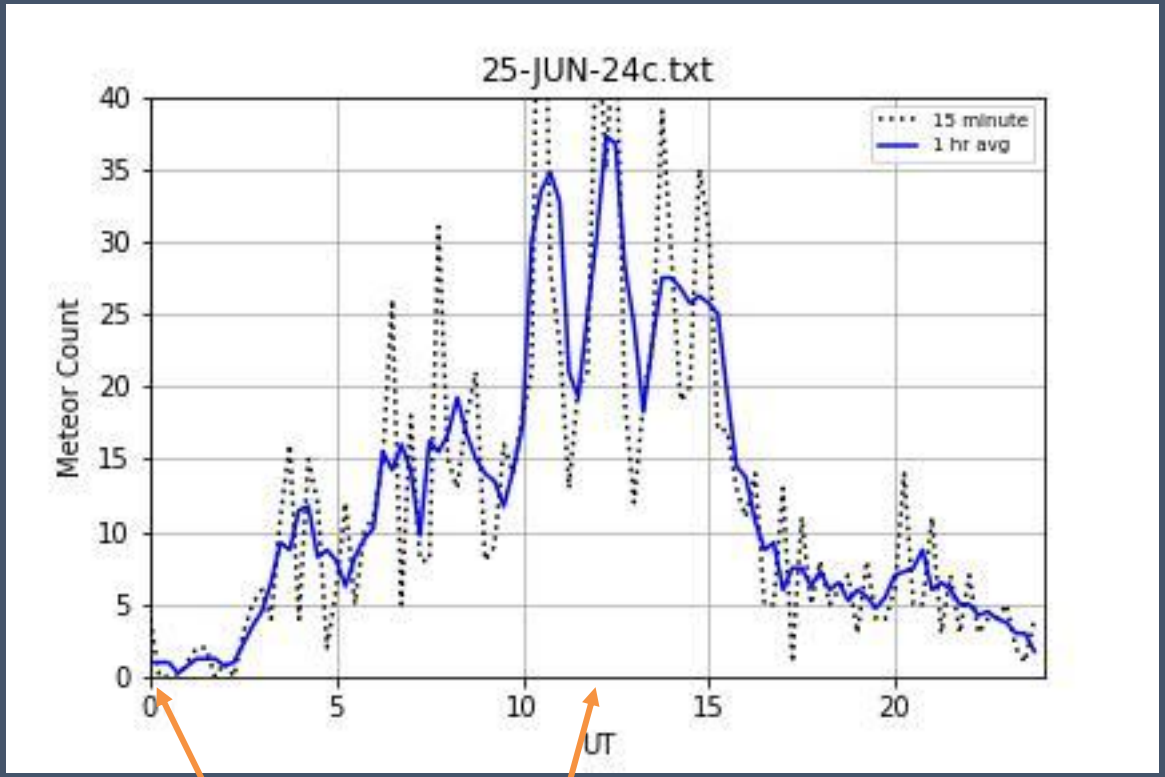


N0FW WG2Z +00 FN20
CQ KB1HY FN31
40.332864, -74.445801
41.874533, -73.022761




Meteor Scatter Ellipsoids for Huntsville AL to MSK144 Stations - 0 deg Radiant El
Footprint of specular ellipsoid
K2DRH
NO3I
W8DPK
AB5CC
Green is 10m
Blue is 6m
Magenta is 2m
Cyan is aircraft scatter

Digital TV pilot tone counts show diurnal variation

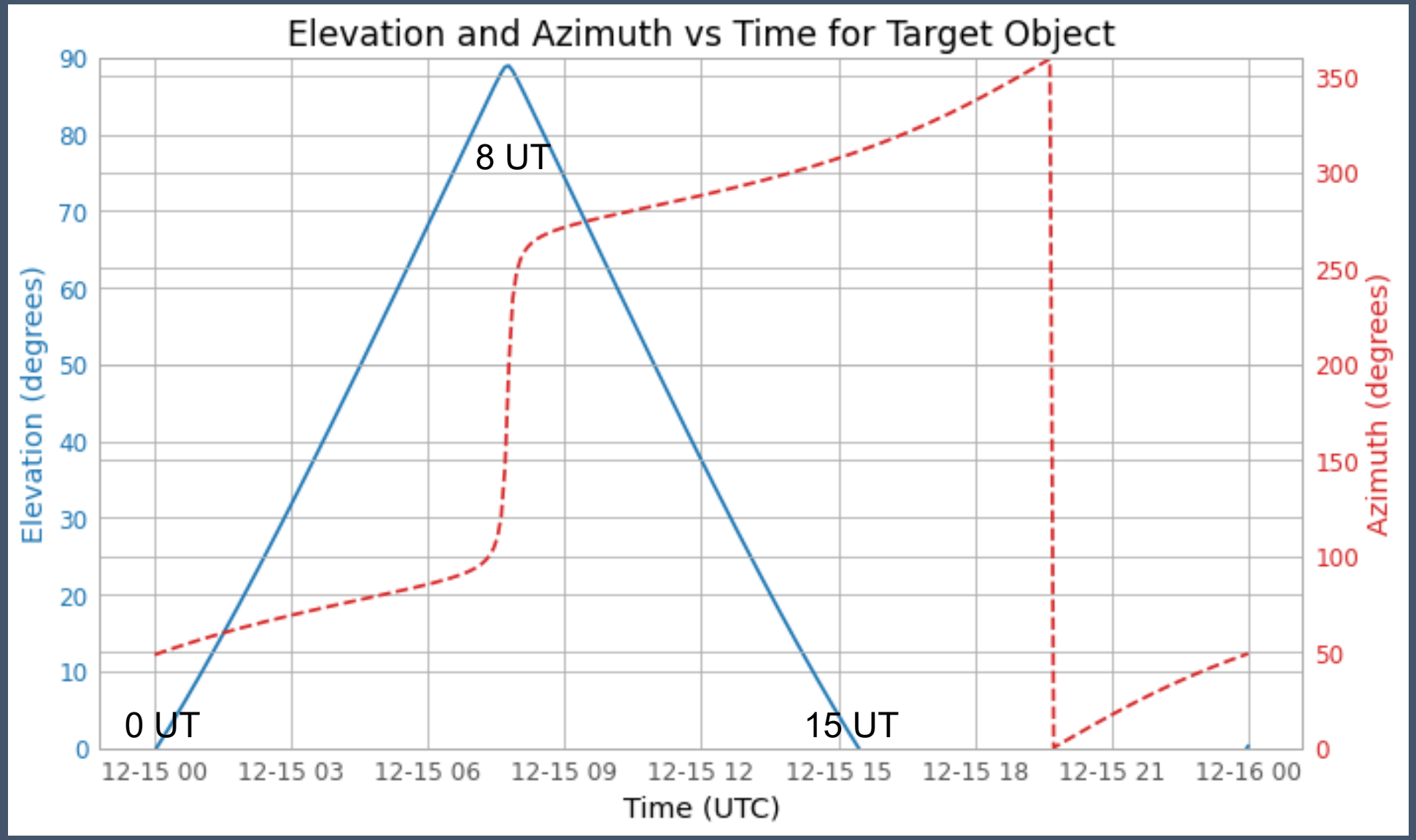


Sunset

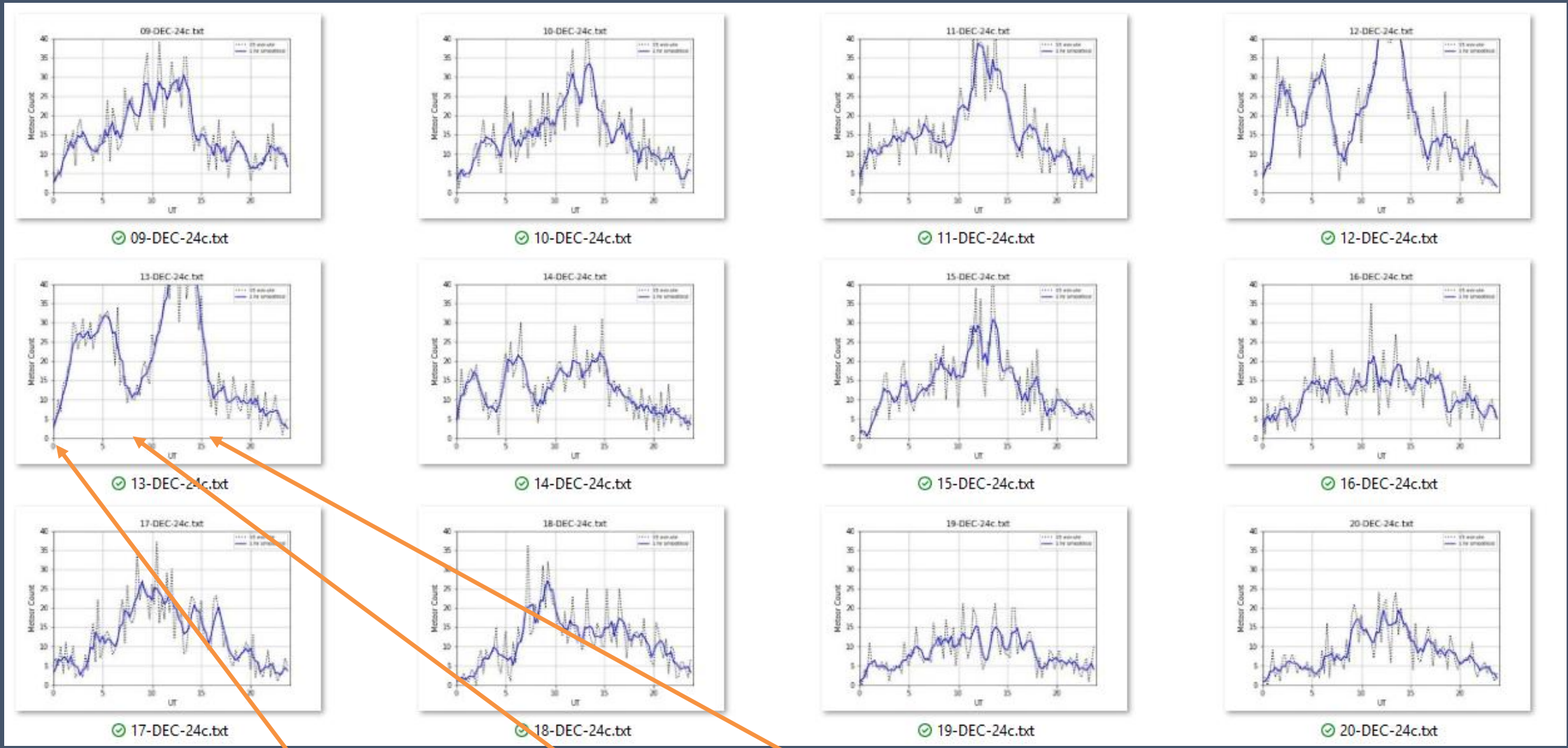
Sunrise

From MSFC ARC NN4SA
DTV channel 3, 60.3085 USB
Icom R8500
Dipole at 6ft
Suggs count software

Geminids radiant moves almost through zenith in north AL



Geminids December 2024 from NN4SA DTV receiver



Radiant rise Radiant at zenith Radiant set

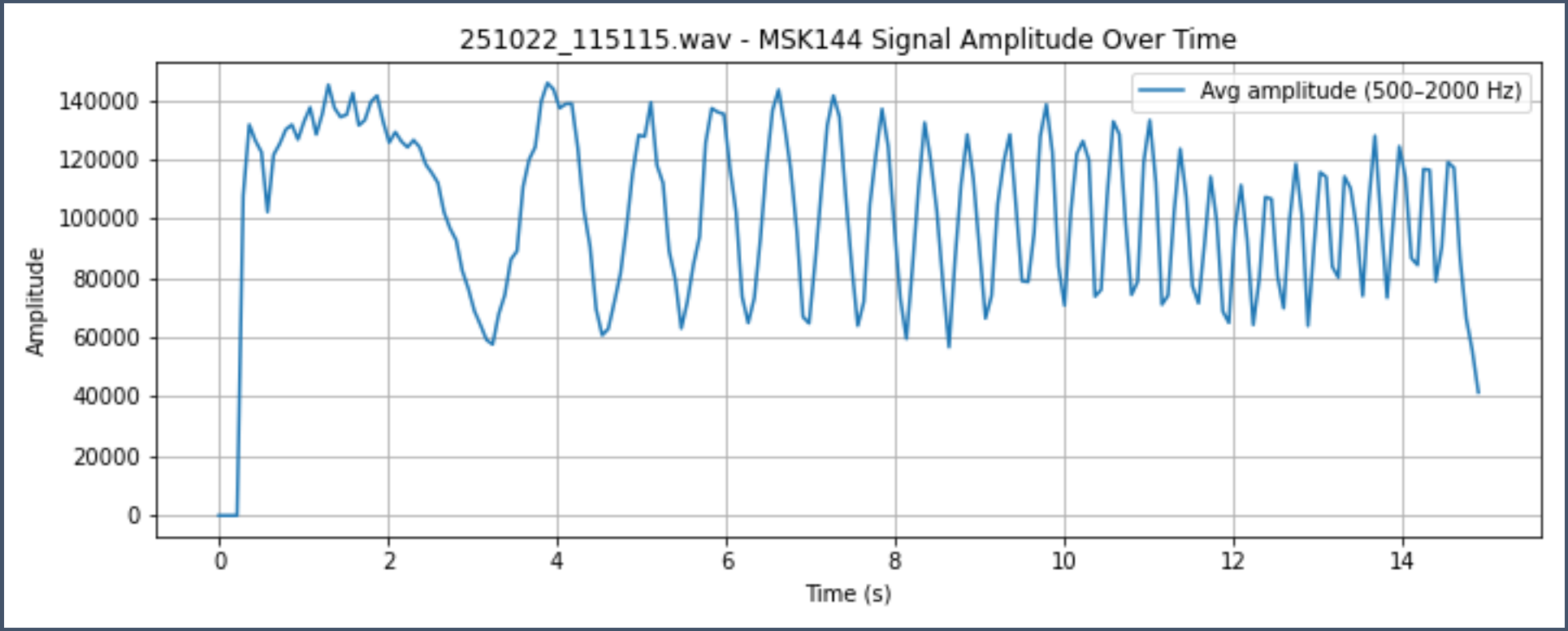
“Meteor-wrongs”

Various other propagation modes can result in MSK144 decodes

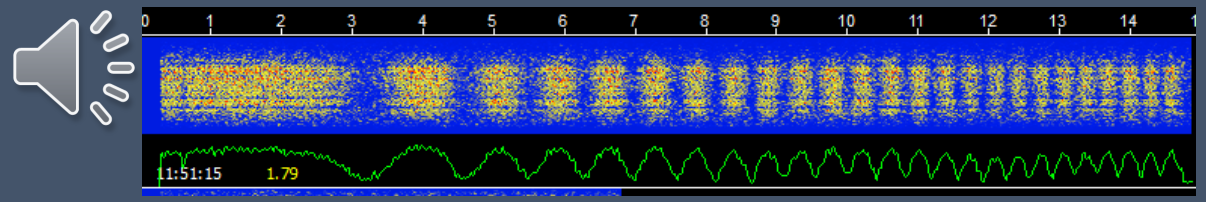
- Sporadic E – during Perseids on 6m
- F-layer propagation – during Geminids on 10m
- Tropospheric ducting
- Aircraft scatter (examples next)

Rejection of these modes are why we are initially focusing on underdense meteors for MSQP

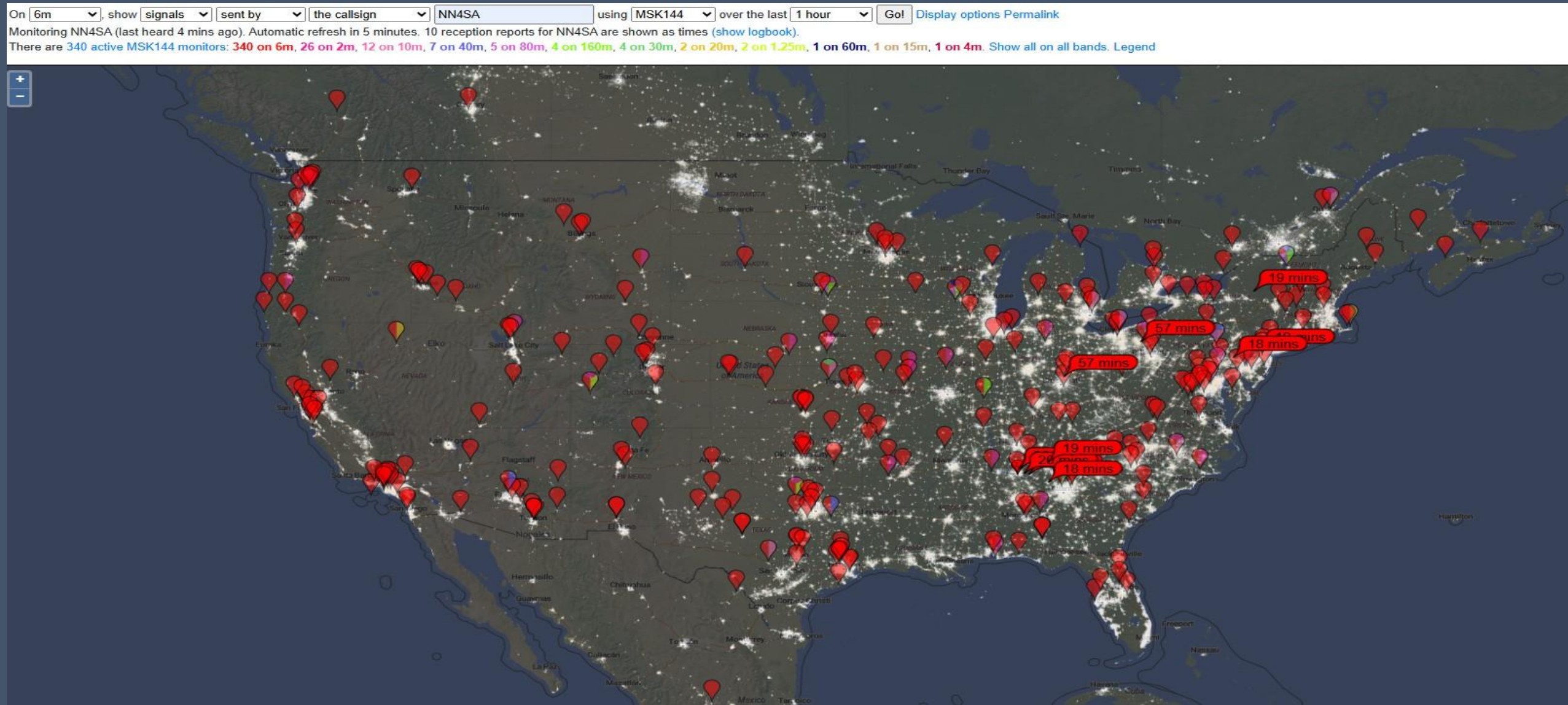
Aircraft scatter 6m Orionids from NN4SA



K5HPT W4HP R+03
EM75 North of Chattanooga
148 km distance from MSFC
35.178479, -85.187124



PSK Reporter 6m spots for NN4SA Geminids 14 Dec 2025

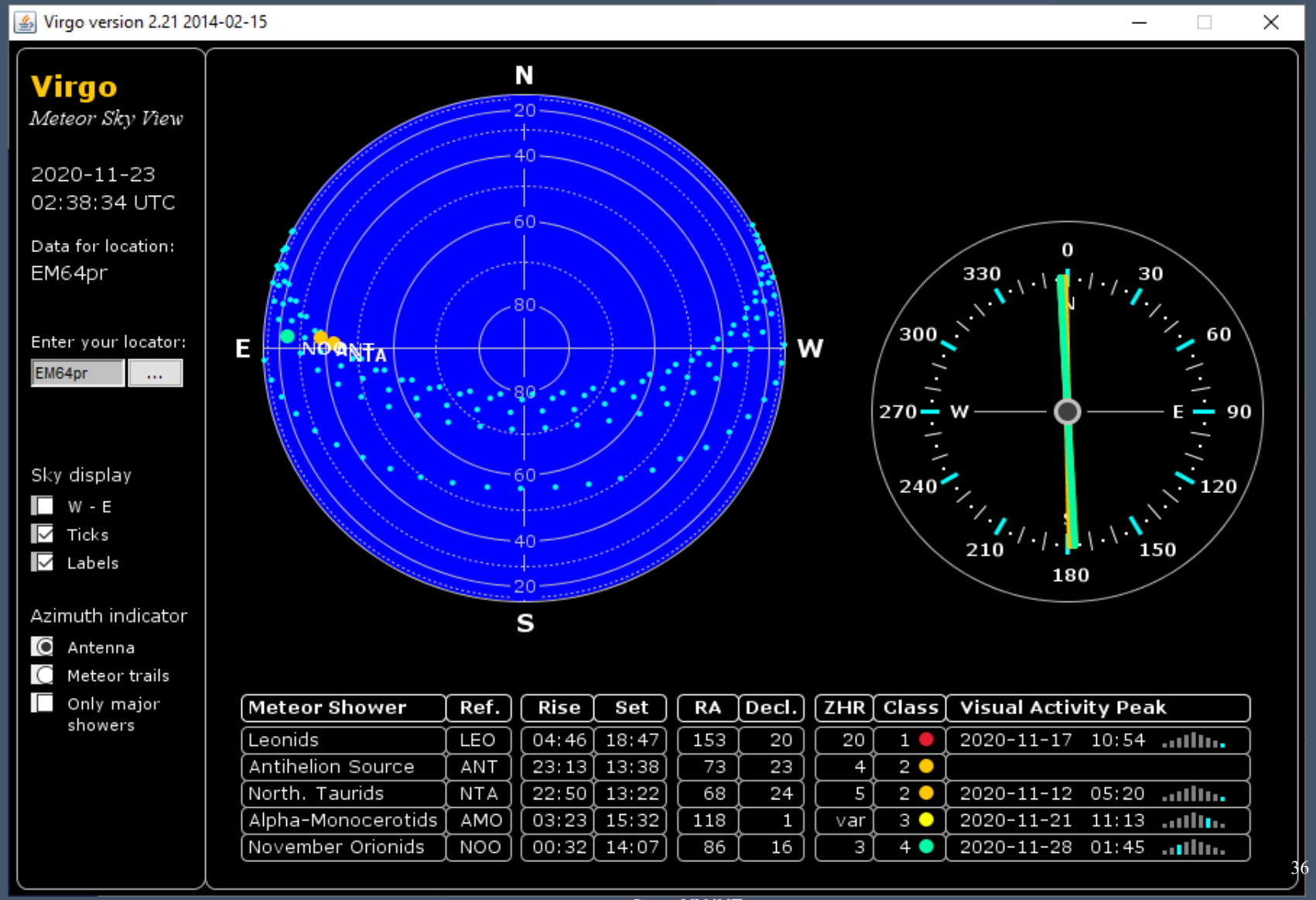

On 6m , show signals sent by the callsign NN4SA using MSK144 over the last 1 hour Go! Display options Permalink
Monitoring NN4SA (last heard 4 mins ago). Automatic refresh in 5 minutes. 10 reception reports for NN4SA are shown as times (show logbook).
There are 340 active MSK144 monitors: 340 on 6m, 26 on 2m, 12 on 10m, 7 on 40m, 5 on 80m, 4 on 160m, 4 on 30m, 2 on 20m, 2 on 1.25m, 1 on 60m, 1 on 15m, 1 on 4m. Show all on all bands. Legend
19 mins
57 mins
18 mins
57 mins
19 mins
18 mins

Pinjockey.net QSO coordination

Enter your message here [ ] Go!

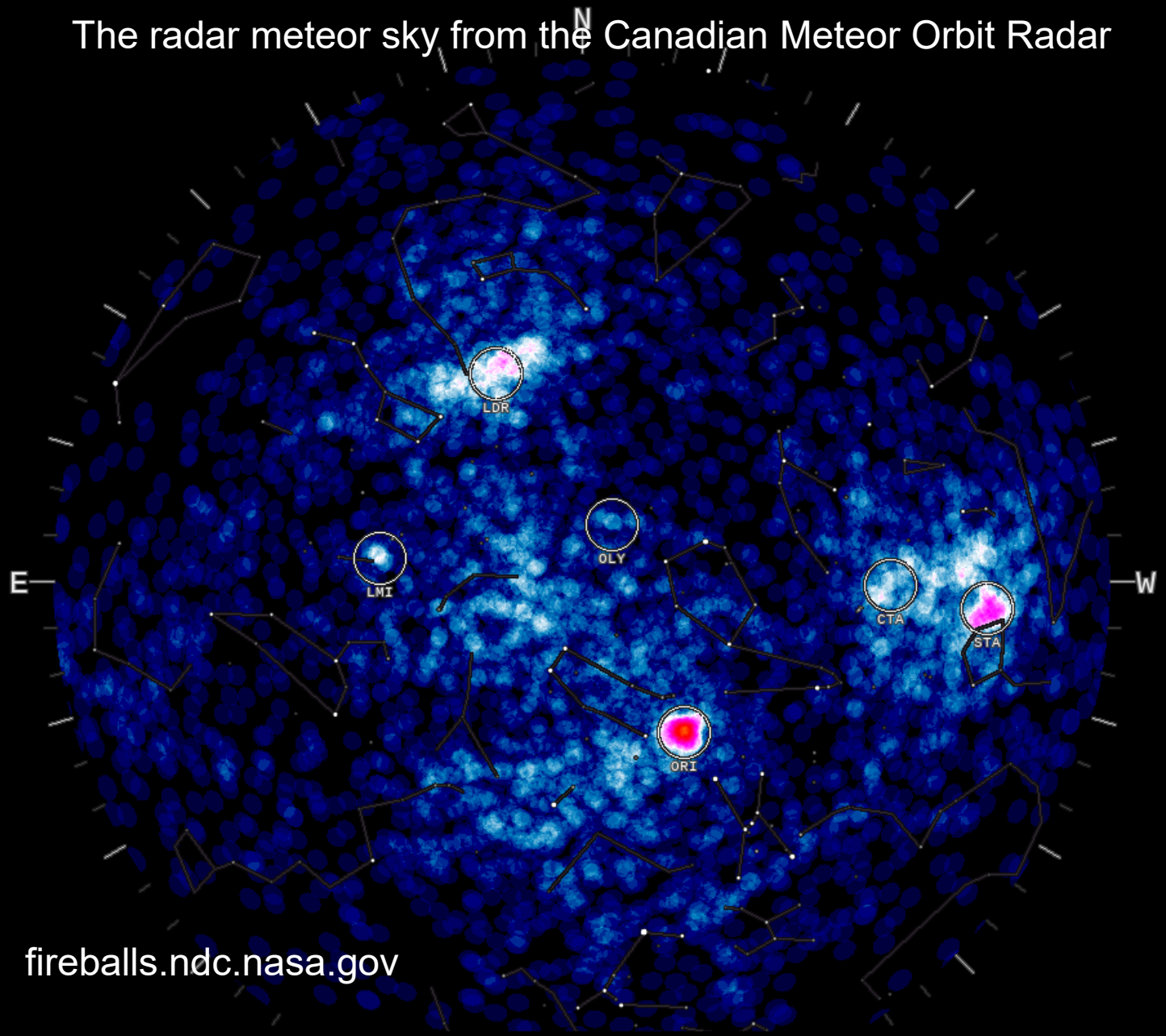
```
DDMMM  UTC
29Jul 11:49 KK0U thanks Jim. No joy with Andy   (NN4NT Rob AL EM64pr )
29Jul 11:48 114430  -6  1.6 1515 &  ++++++ W5TRL 73         U.S.A.      (XE2YWH/2M/6M Jose xx DL92ag )
29Jul 11:48 NN4NT, nothing this end, hv stopped calling (KA2UQW Andy NJ FN20xh )
29Jul 11:48 WA2FZW - GM John, my noise is bad this morning in your direction    (WU5X Jim AL EM64ro )
29Jul 11:47 NN4NT -6 to +1 here now     (KK0U Jim MO EM48to )
29Jul 11:46 114600   0  4.6 1497 &  CQ WU5X EM64 - GM Jim - Would answer but very noisy your direction today    (WA2FZW/6M/2M John NJ FN20tp )
29Jul 11:45 I had to work one a while back with the rotator stuck at 270 degrees - At least it wasn't in some super dumb direction      (WA2FZ
29Jul 11:44 yea too true Murphy is a dick       (K2DRH Bobtwo IL EN41vr )
29Jul 11:43 CQ Stopped - 6&2    (WA2FZW/6M/2M John NJ FN20tp )
29Jul 11:43 N0AN RR understand  (K2DRH Bobtwo IL EN41vr )
29Jul 11:43 K2DRH - It wuit because it was during a contest!    (WA2FZW/6M/2M John NJ FN20tp )
29Jul 11:42 NN4NT, switched to calling u 2nd    (KA2UQW Andy NJ FN20xh )
29Jul 11:42 EA2FZW nwvwe did really figure out why 2M quit during our contest QSO - workked fine later  (K2DRH Bobtwo IL EN41vr )
29Jul 11:42 Tnx again Hasan     (WA2FZW/6M/2M John NJ FN20tp )
29Jul 11:42 114115  12 10.1 1495 &  CQ WA2FZW FN20      (N0AN/6M/500/5EL Hasan IA EN22xc )
29Jul 11:41 K2DRH: I went to CSVHF many years ago when it was in Cedar Rapids, but I don't travel much any more. I don't trust my eyesight.
29Jul 11:41 113830 2 1.0 1542 & KF2ZQ W8GEX 73, TU Joe  (KF2ZQ Scott NY FN30hu )
29Jul 11:41 Tnx Bob     (WA2FZW/6M/2M John NJ FN20tp )
29Jul 11:40 Tnx Hasan   (WA2FZW/6M/2M John NJ FN20tp )
```

Virgo software calculates the optimal geometry swan.ms is a similar web-based tool

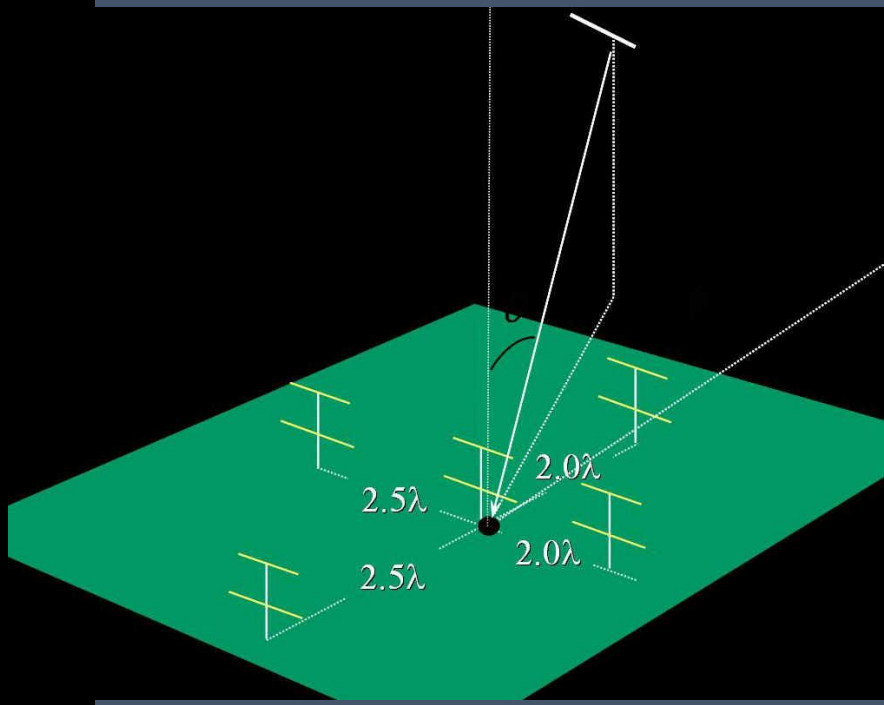


Orionids 21 October 2025

The radar meteor sky from the Canadian Meteor Orbit Radar



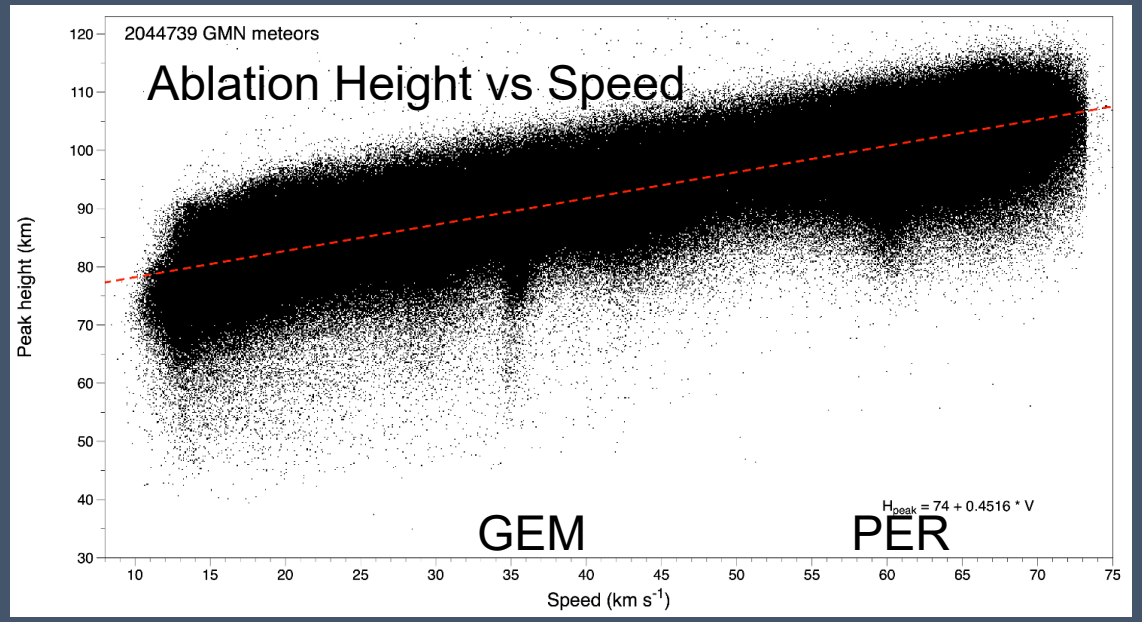
fireballs.ndc.nasa.gov



https://aquarid.physics.uwo.ca/research/radar/cmor_basics.html

Current and Future Work

- Nina Tormann (see her poster) is looking at Tun (duration) vs wavelength
- Need to look at Pr, signal strength vs wavelength
- Need to look at Tun and Pr for different showers which are different speed, ablation altitude (echo ceiling height), and electron diffusion time
- There may be interesting signatures for other propagation modes

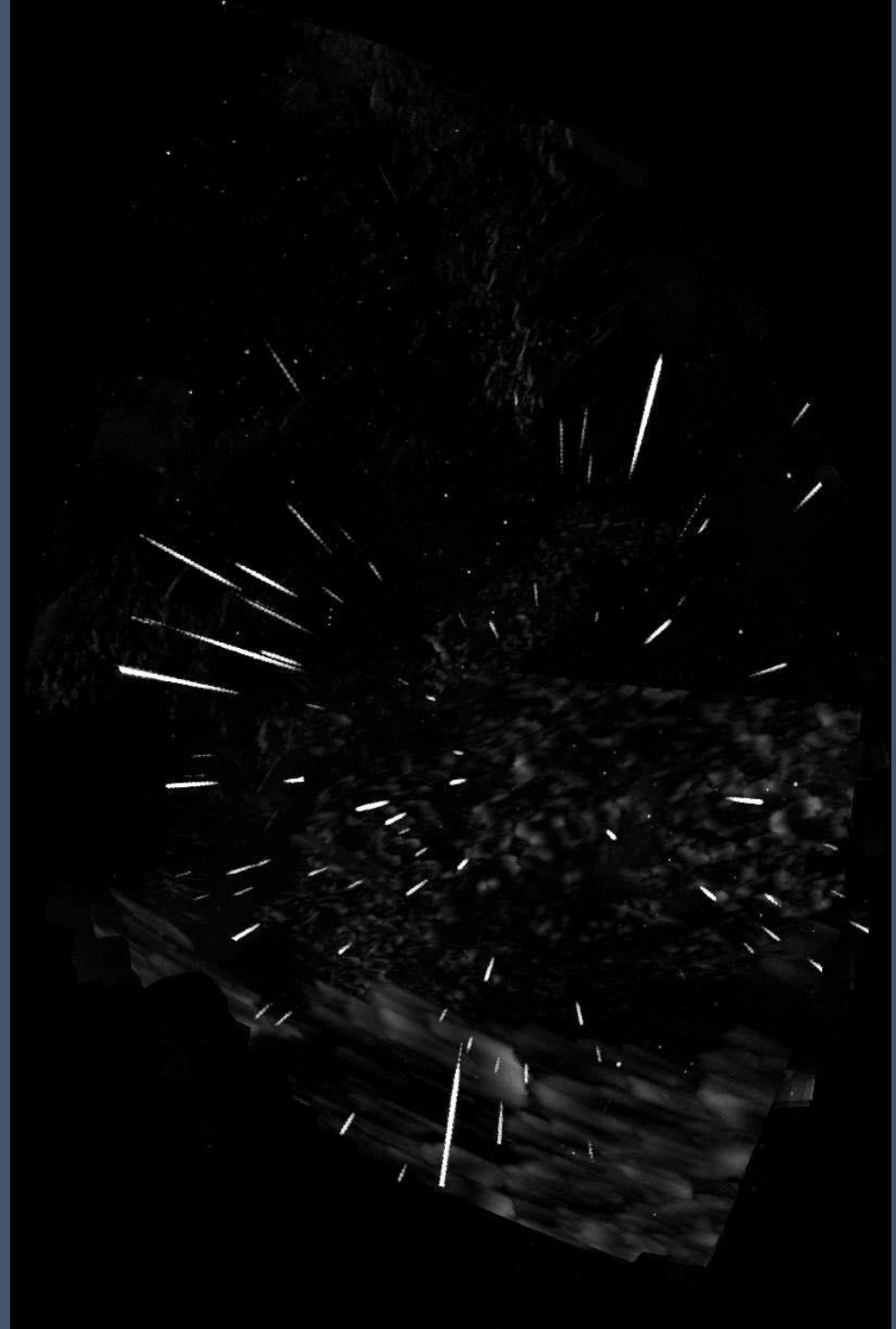


Graphic courtesy of
Bill Cooke/NASA/MEO

Plot is data from over 2 million meteors observed by Global Meteor Network cameras

Summary

- The ionization trail from a grain-of-sand sized meteor ablating in the atmosphere can have the radar cross section of a battleship
- You can use meteor scatter any time but it is easier during meteor showers and during the morning hours
  - More sporadic meteors are visible around sunrise
  - Meteor showers have higher rates of large meteoroids
- Certain path azimuths are favored due to the specular reflection constraint and radiant location
- Data collected during the MSQP can provide tests for some fundamental meteor scatter questions



Links and Additional Resources

https://fireballs.ndc.nasa.gov

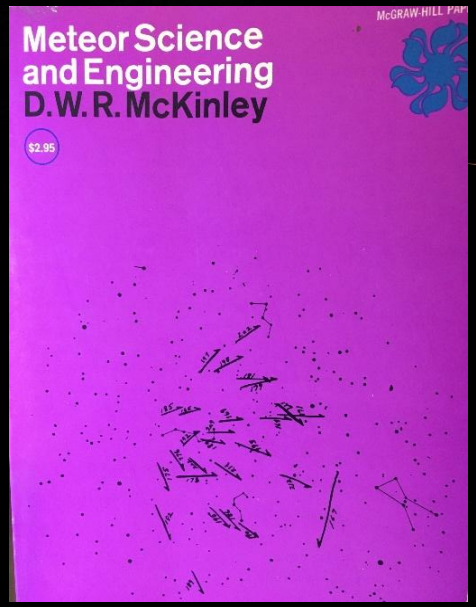
http://pingjockeys.net

CMOR https://aquarid.physics.uwo.ca/research/radar/cmor_basics.html

International Meteor Organization radio observation info

http://www.imo.net/radio/index.html

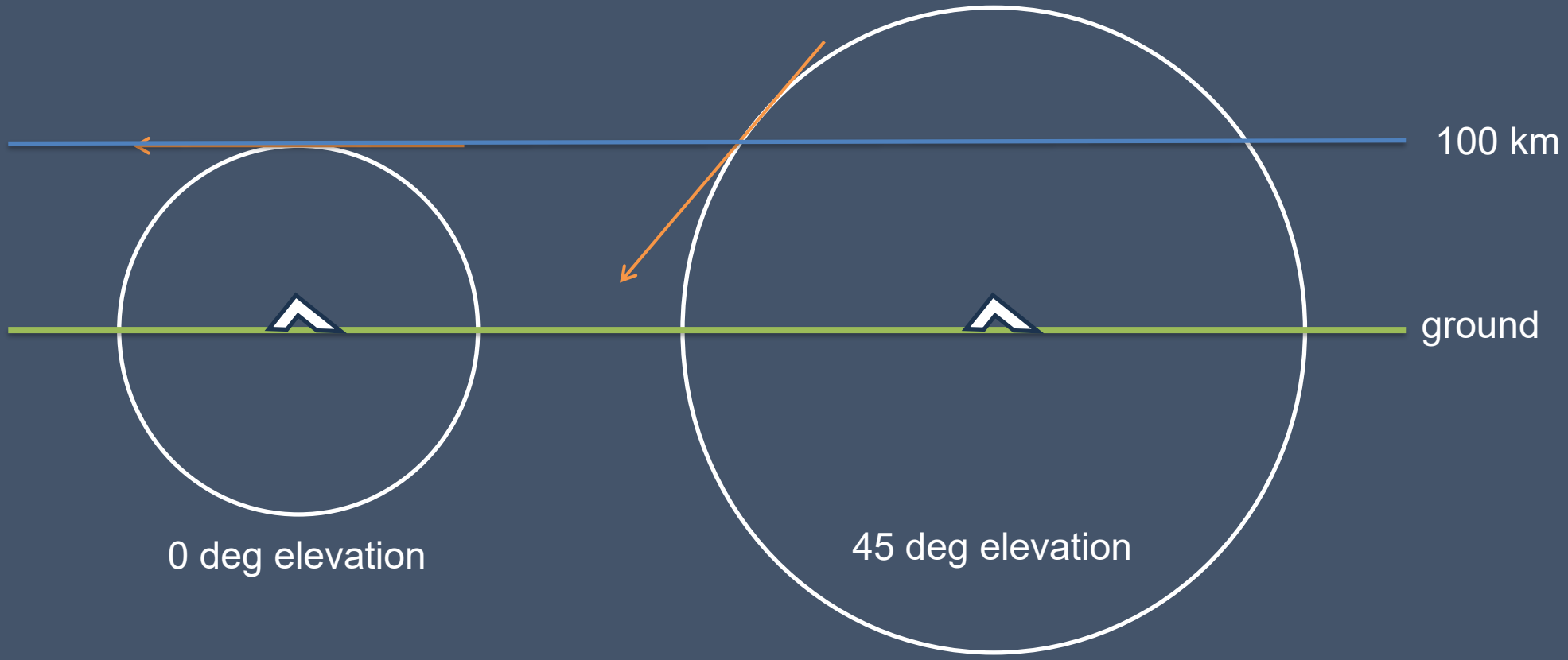
Meteor Science and Engineering by D. W. R. McKinley – 1961



Backup

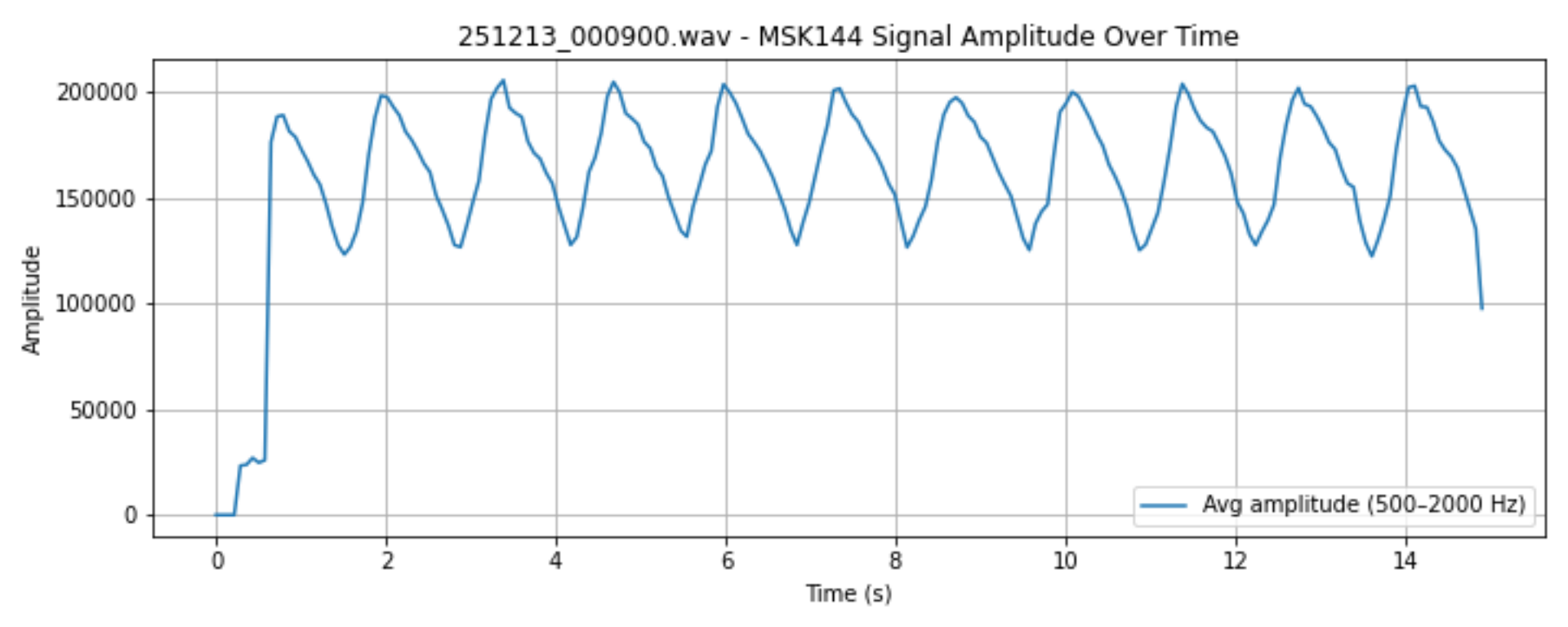
The author and the guy who took the Lyrid meteor picture from ISS, Dr. Don Pettit

Constraining the ellipses with radiant elevation and meteor altitude

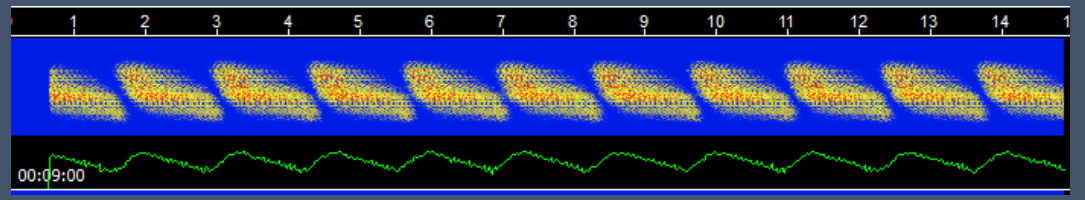


Looking along the major axis of the ellipsoid

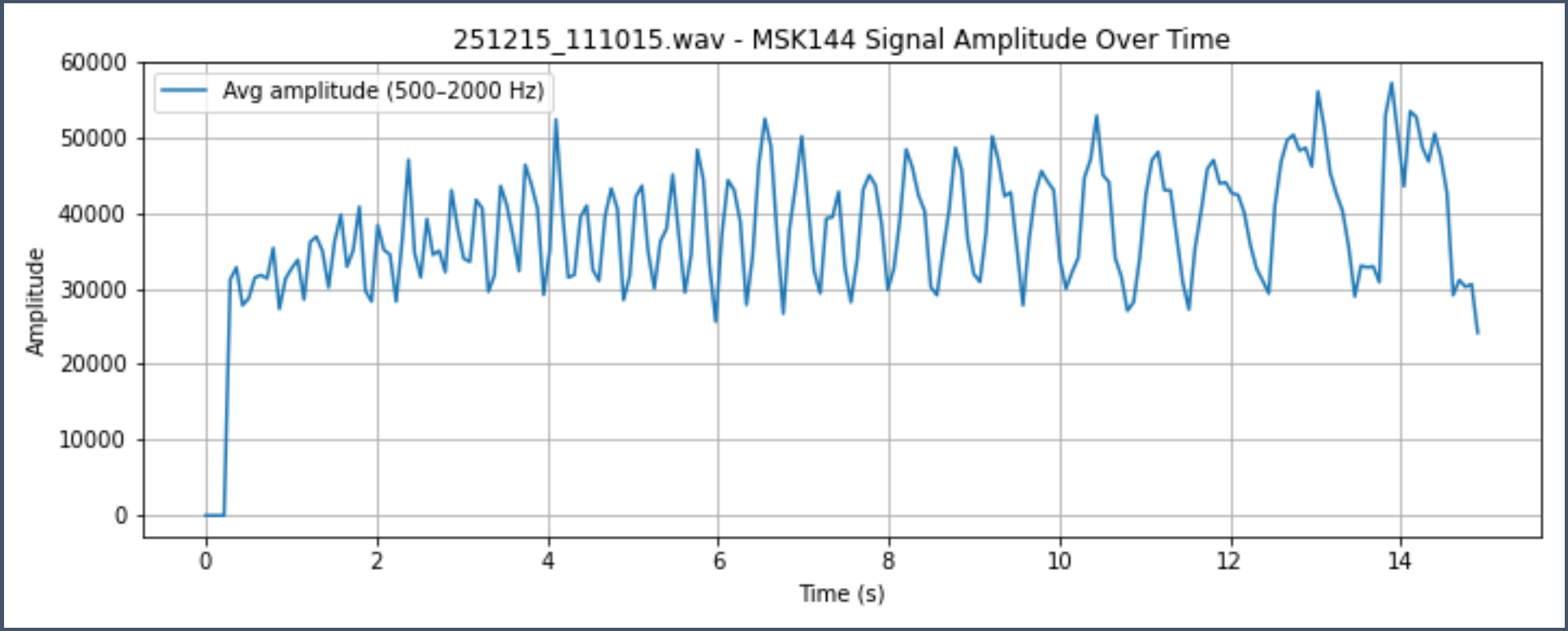
NN4NT 10m during Geminids F layer propagation dispersion?



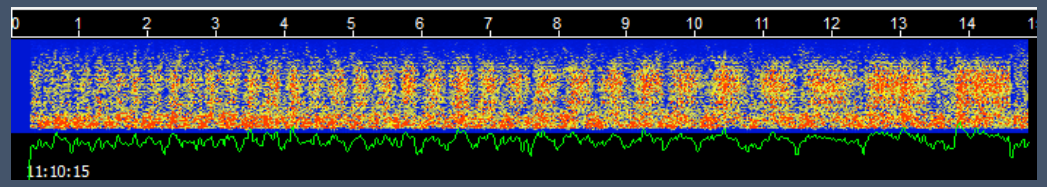
W8VYM KJ6DQR DM13
California



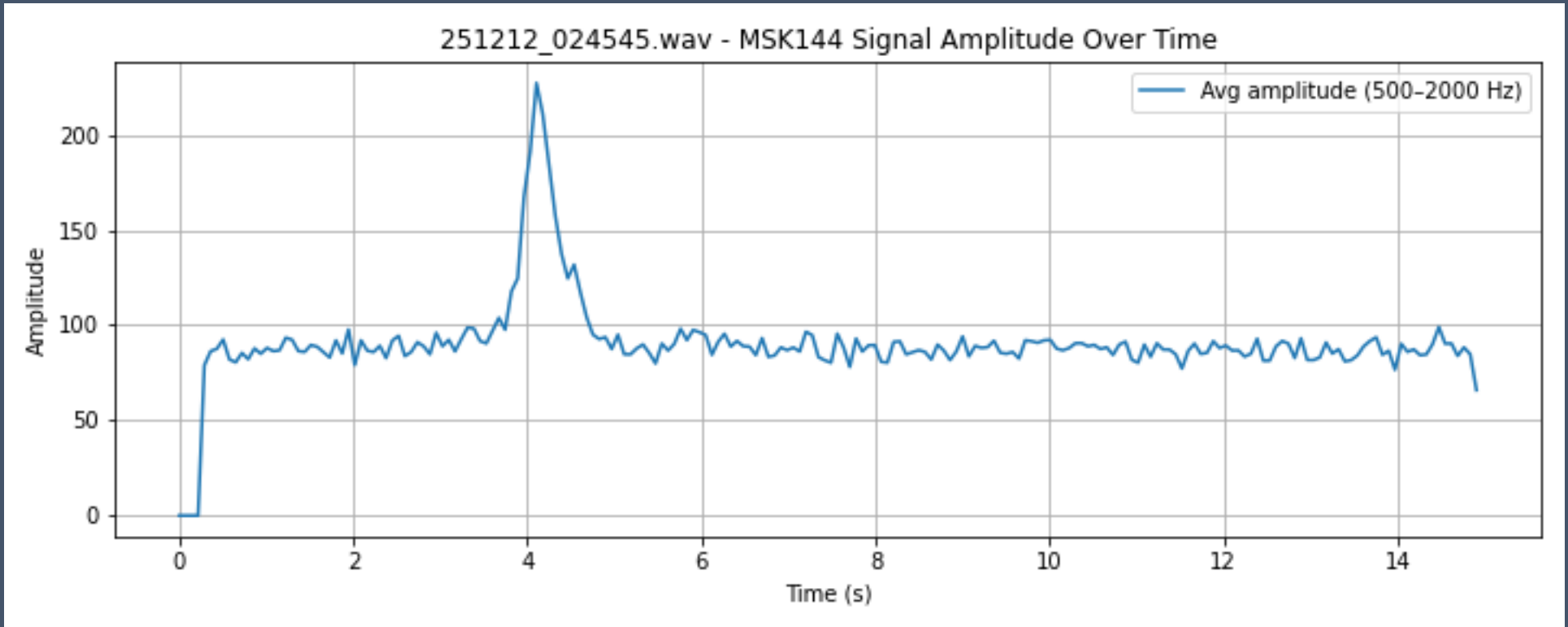
Aircraft scatter 6m during Geminids



K5YT W4HP EM75
North of Chattanooga
35.178479, -85.187124

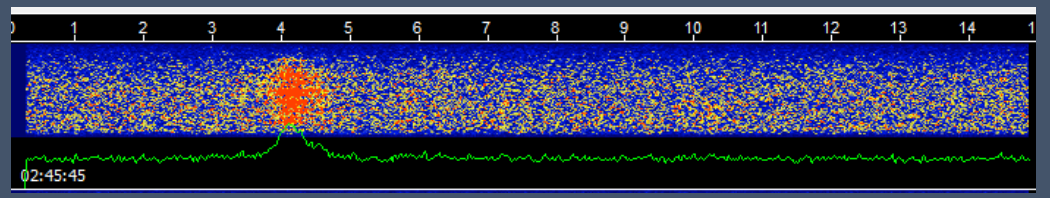


Underdense 10m meteor during Geminids 2025 from NN4SA

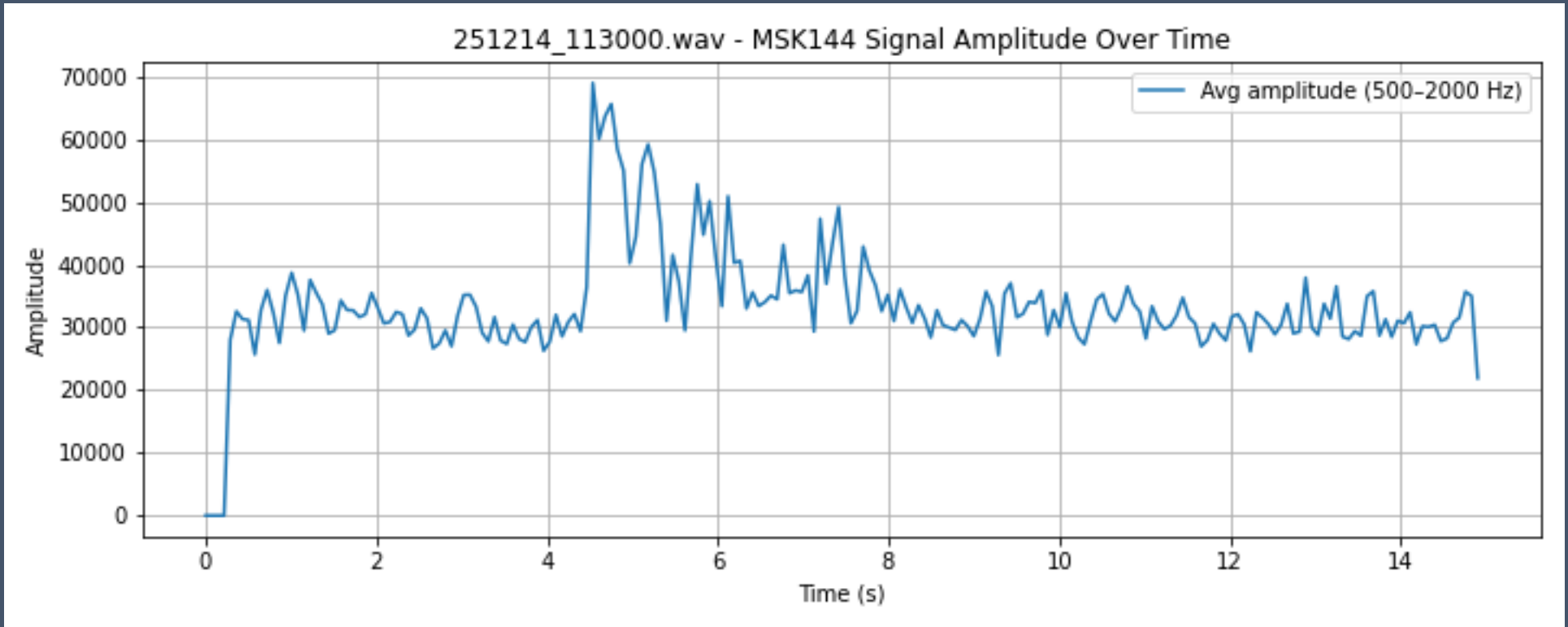


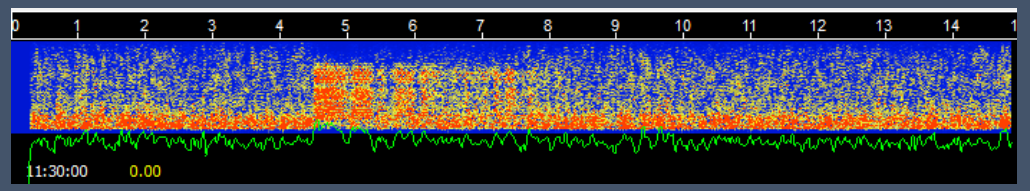
Can't hear it

CQ NX7U FM20

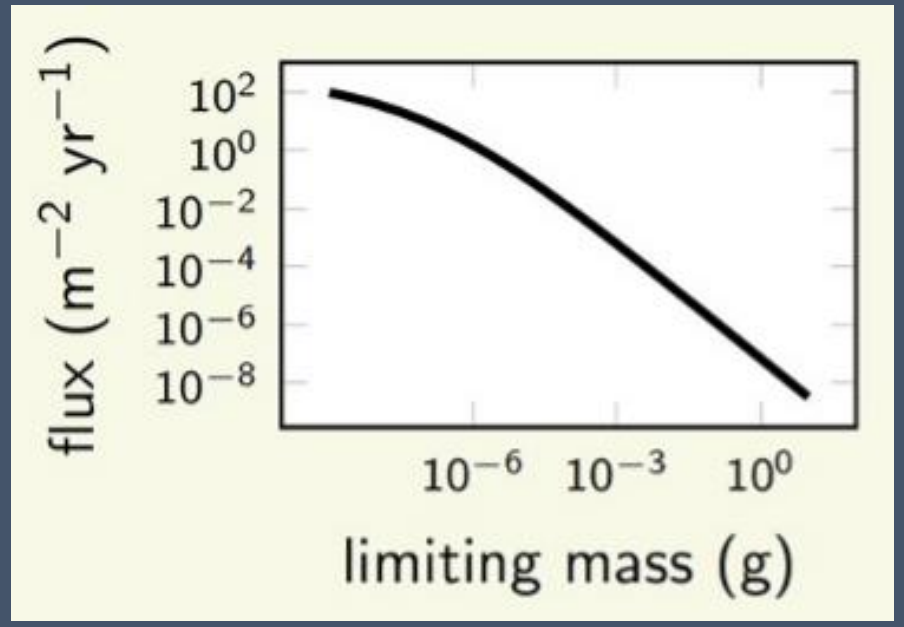


Likely 6m overdense during Geminids from NN4SA

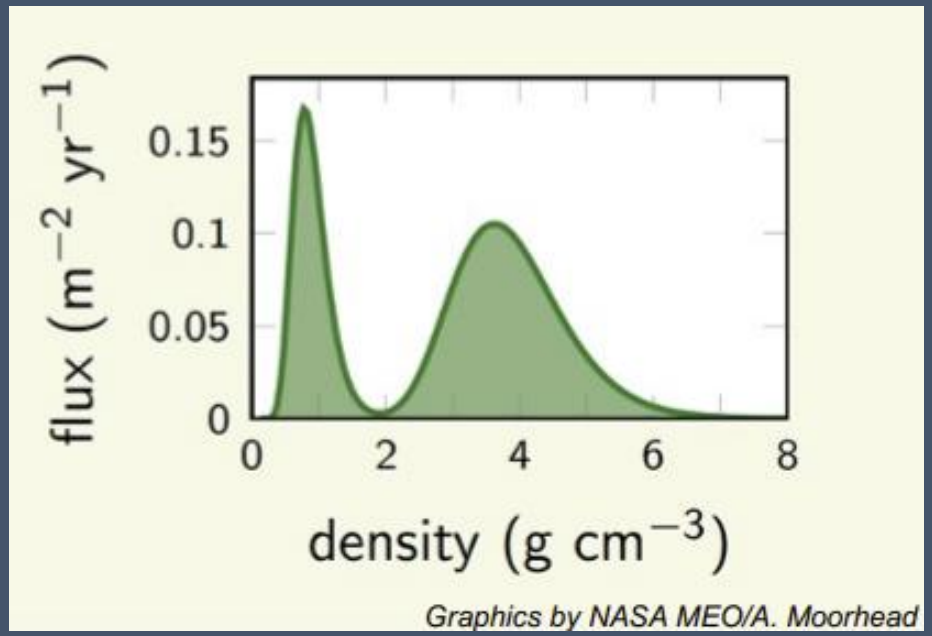




KQ4SY WA4CQG RR73
EM72 Auburn AL
32.609054, -85.531654



Mass and Density Distributions of Meteoroids



Sporadic source speeds are highest from the apex direction

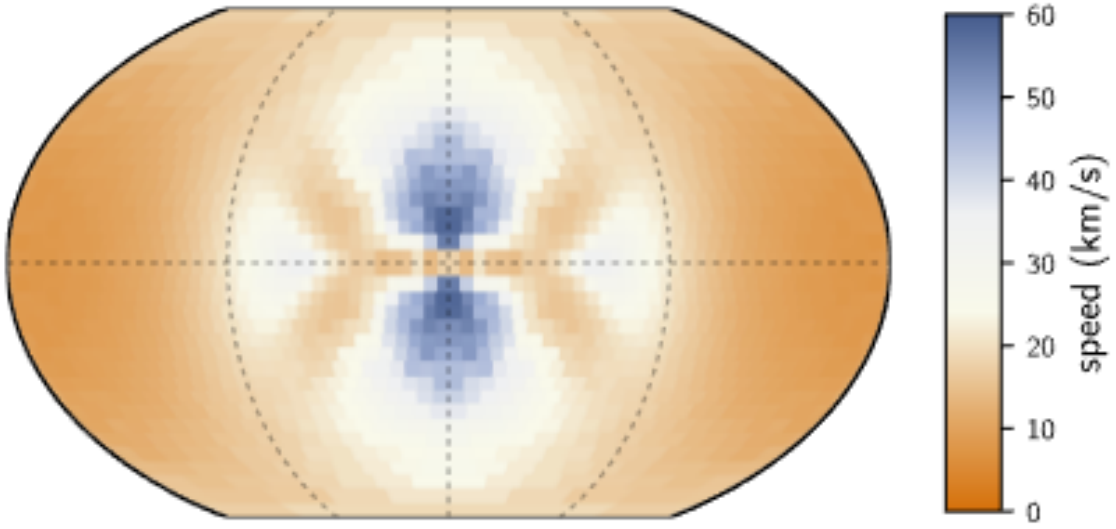


Figure 4. Average interplanetary meteoroid speed as calculated by MEM 3 for a spacecraft that is orbiting the Sun at 1 au but is not near the Earth. Color indicates the average speed of all meteoroids originating from a particular direction, with blue areas corresponding to higher speeds and red to lower. The directionality is plotted in a body-fixed frame, in which the center (0° in azimuth and 0° in altitude) corresponds to the spacecraft's direction of motion.

https://fireballs.ndc.nasa.gov/mem/guide/

Underdense echo

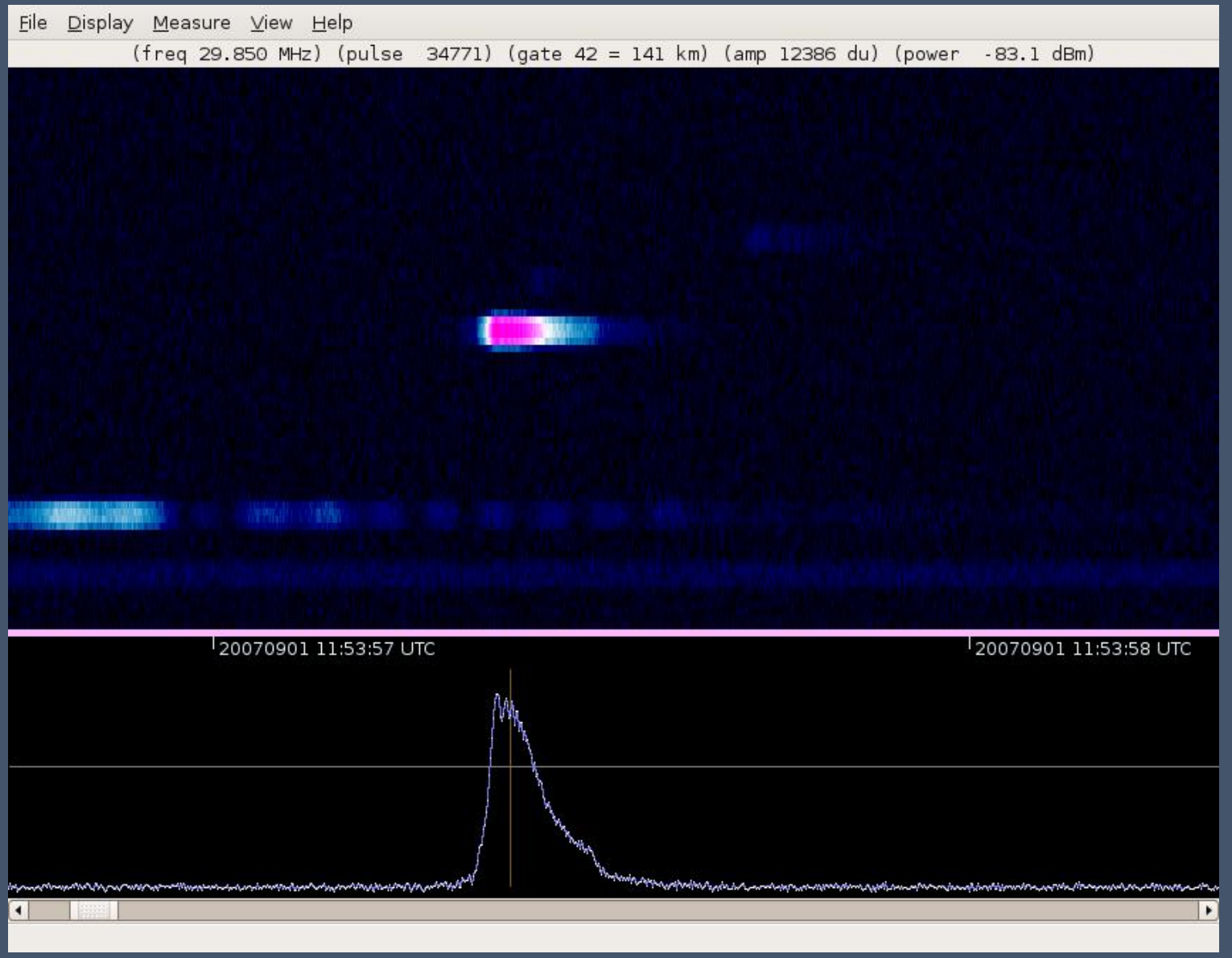

File Display Measure View Help
(freq 29.850 MHz) (pulse 34771) (gate 42 = 141 km) (amp 12386 du) (power -83.1 dBm)
20070901 11:53:57 UTC
20070901 11:53:58 UTC

Diagram from P. Brown, Univ. of Western Ontario, Canadian Meteor Orbit Radar

Overdense echo

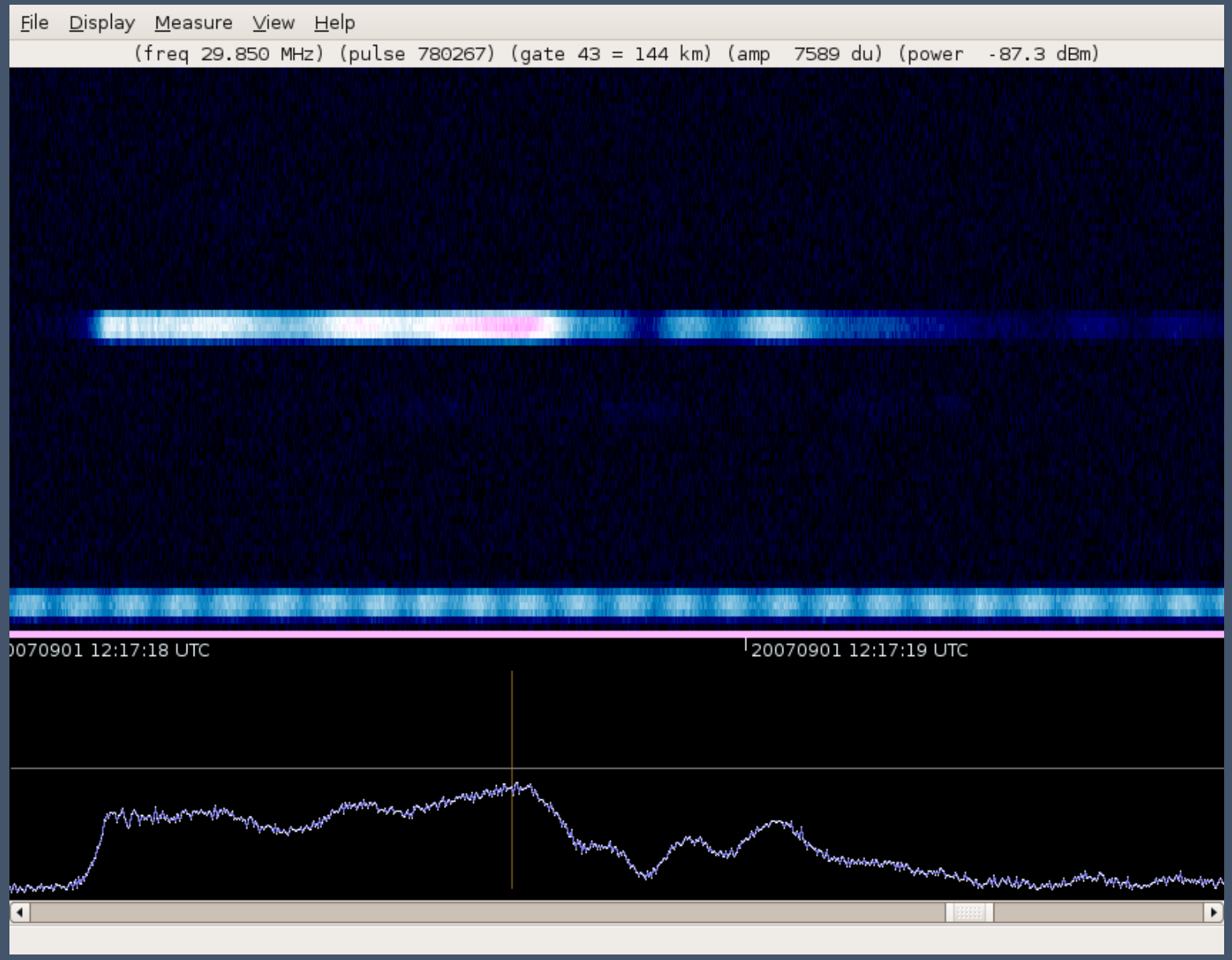
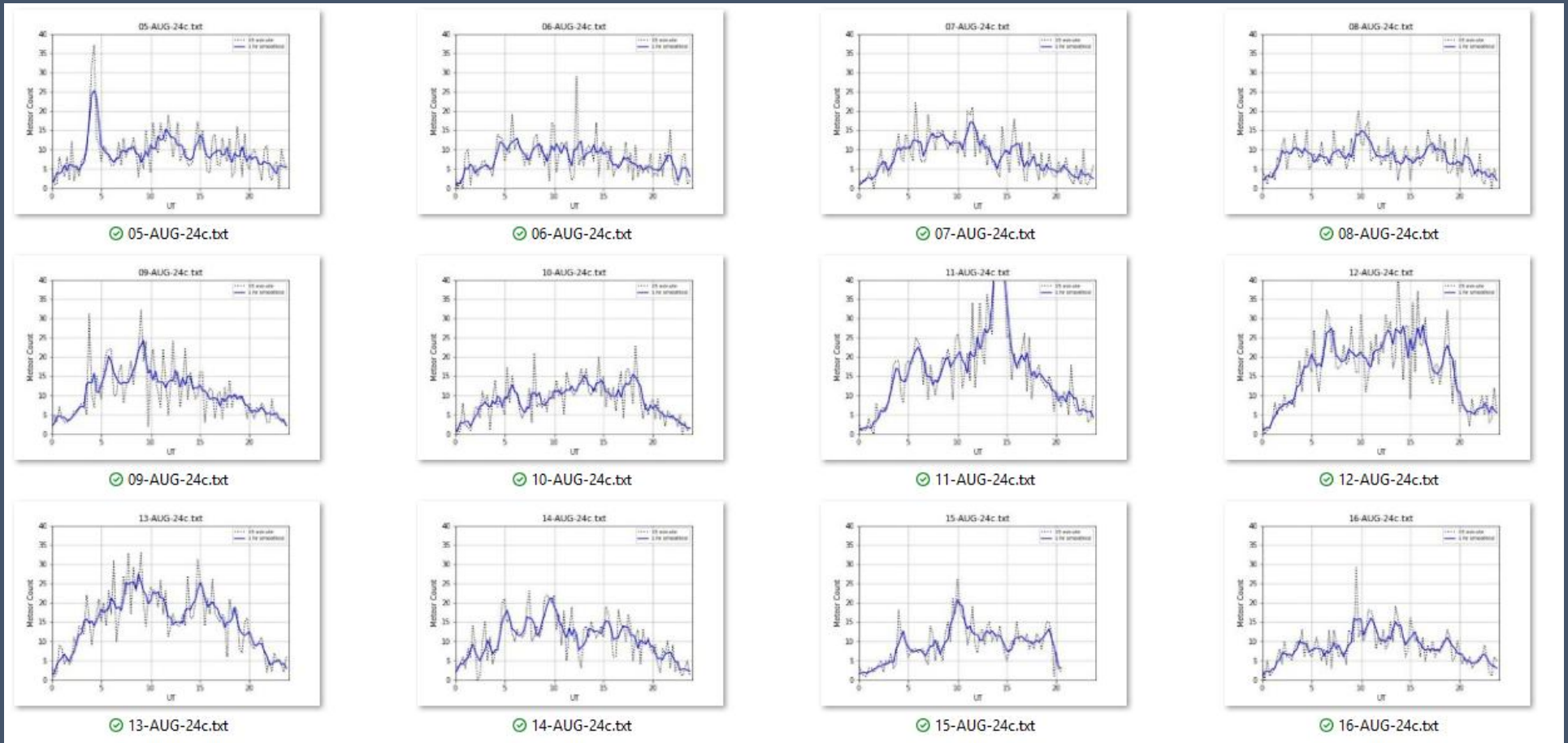
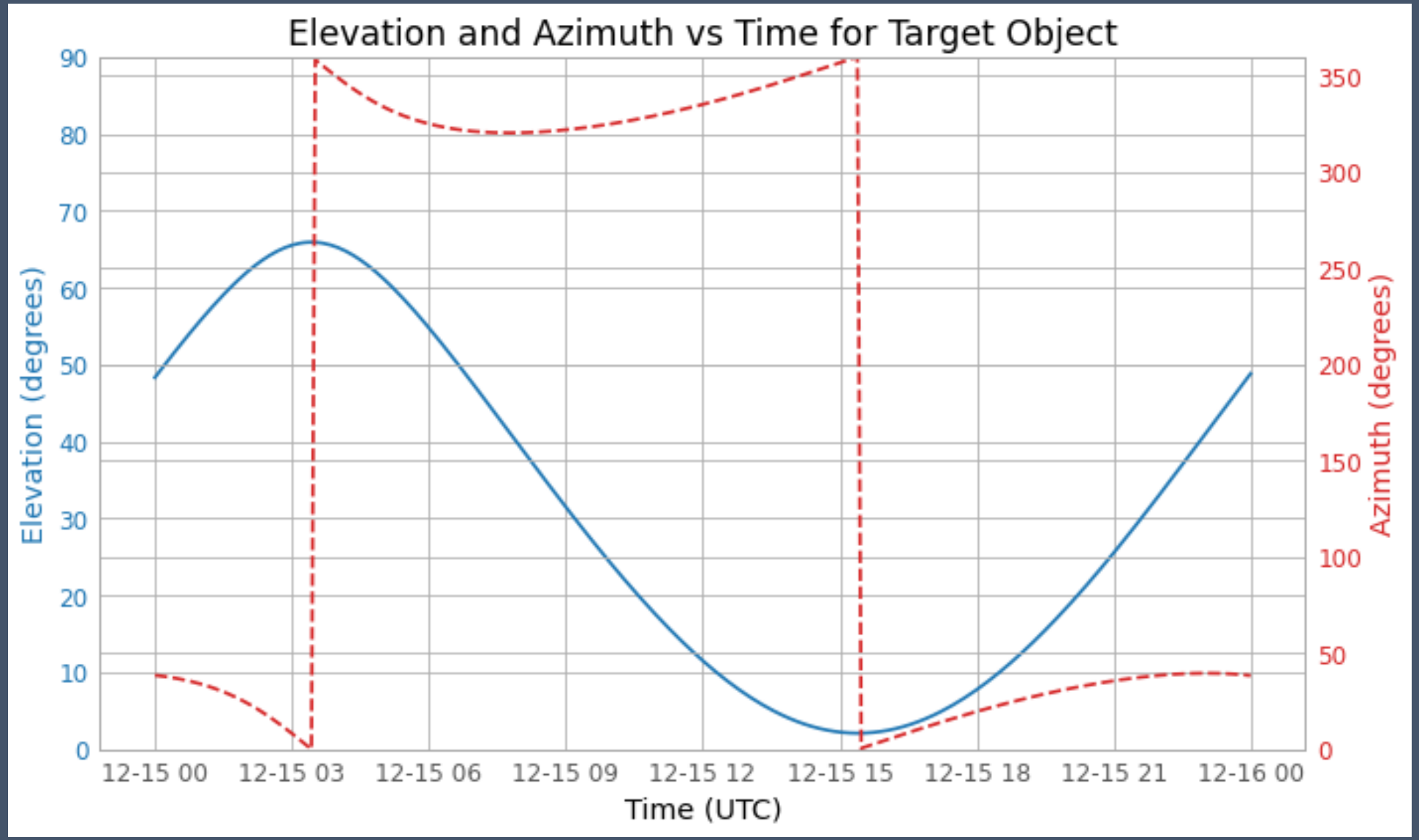

File Display Measure View Help
(freq 29.850 MHz) (pulse 780267) (gate 43 = 144 km) (amp 7589 du) (power -87.3 dBm)
0070901 12:17:18 UTC
20070901 12:17:19 UTC

Diagram from P. Brown, Univ. of Western Ontario, Canadian Meteor Orbit Radar

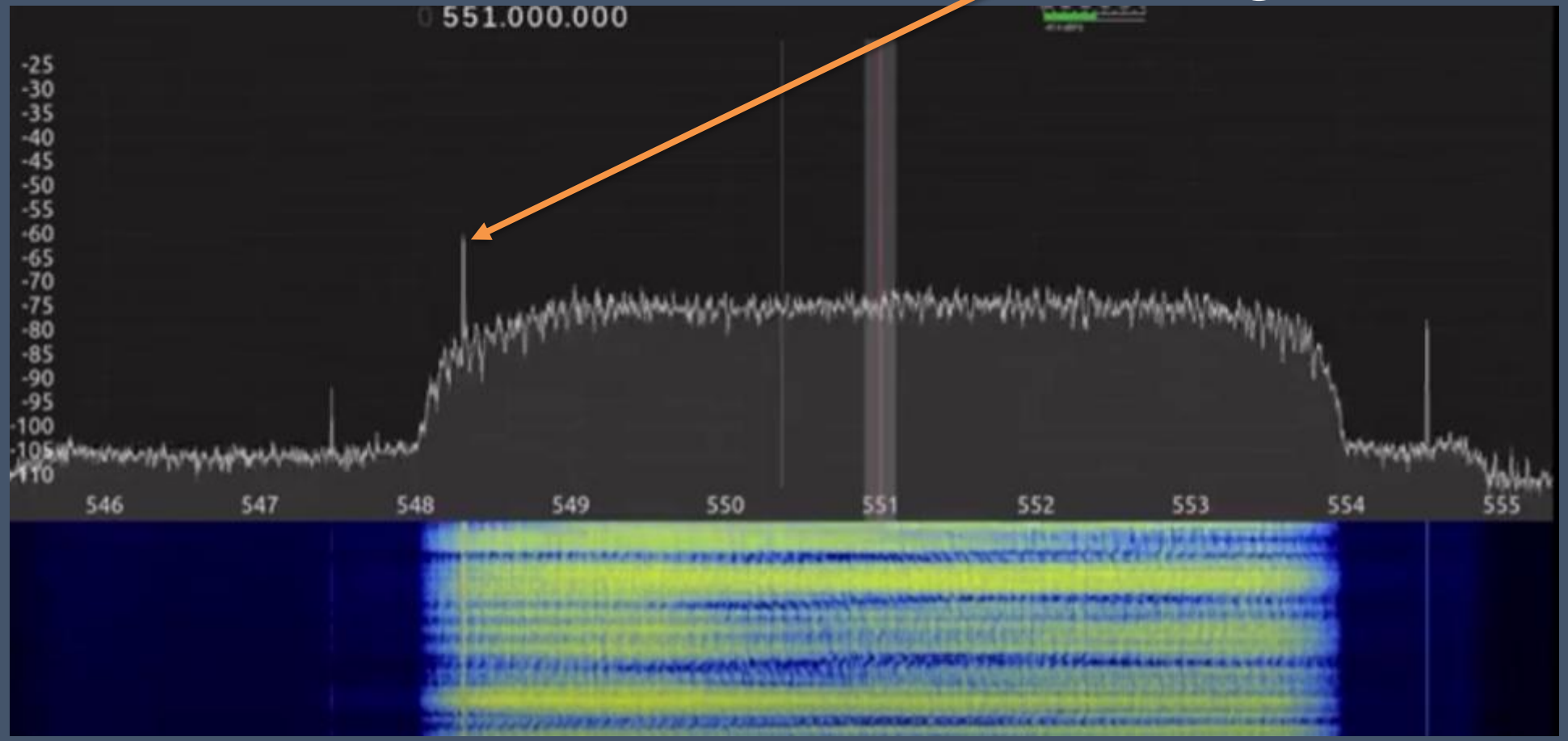
Perseids August 2024



Perseids radiant location

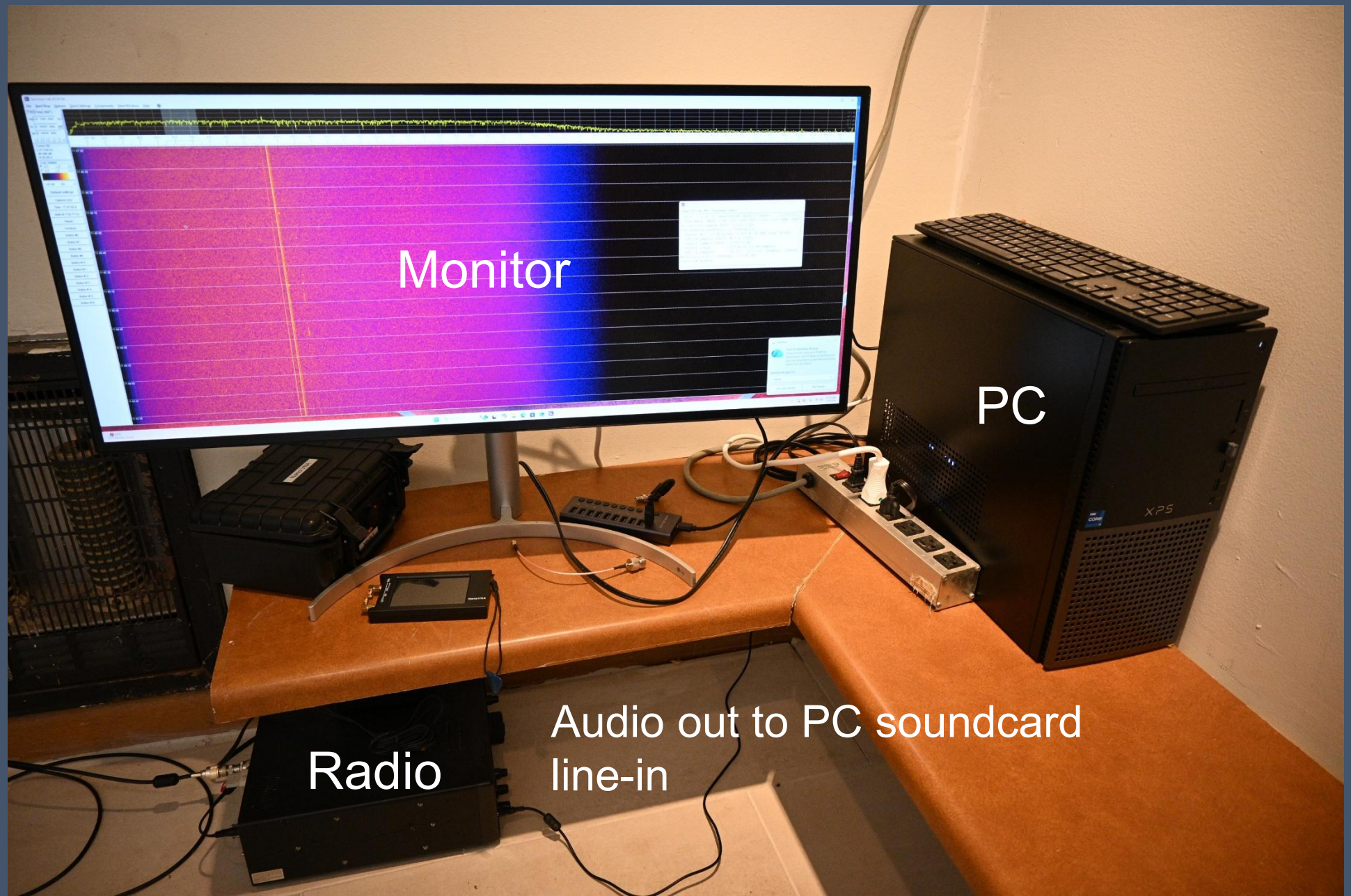


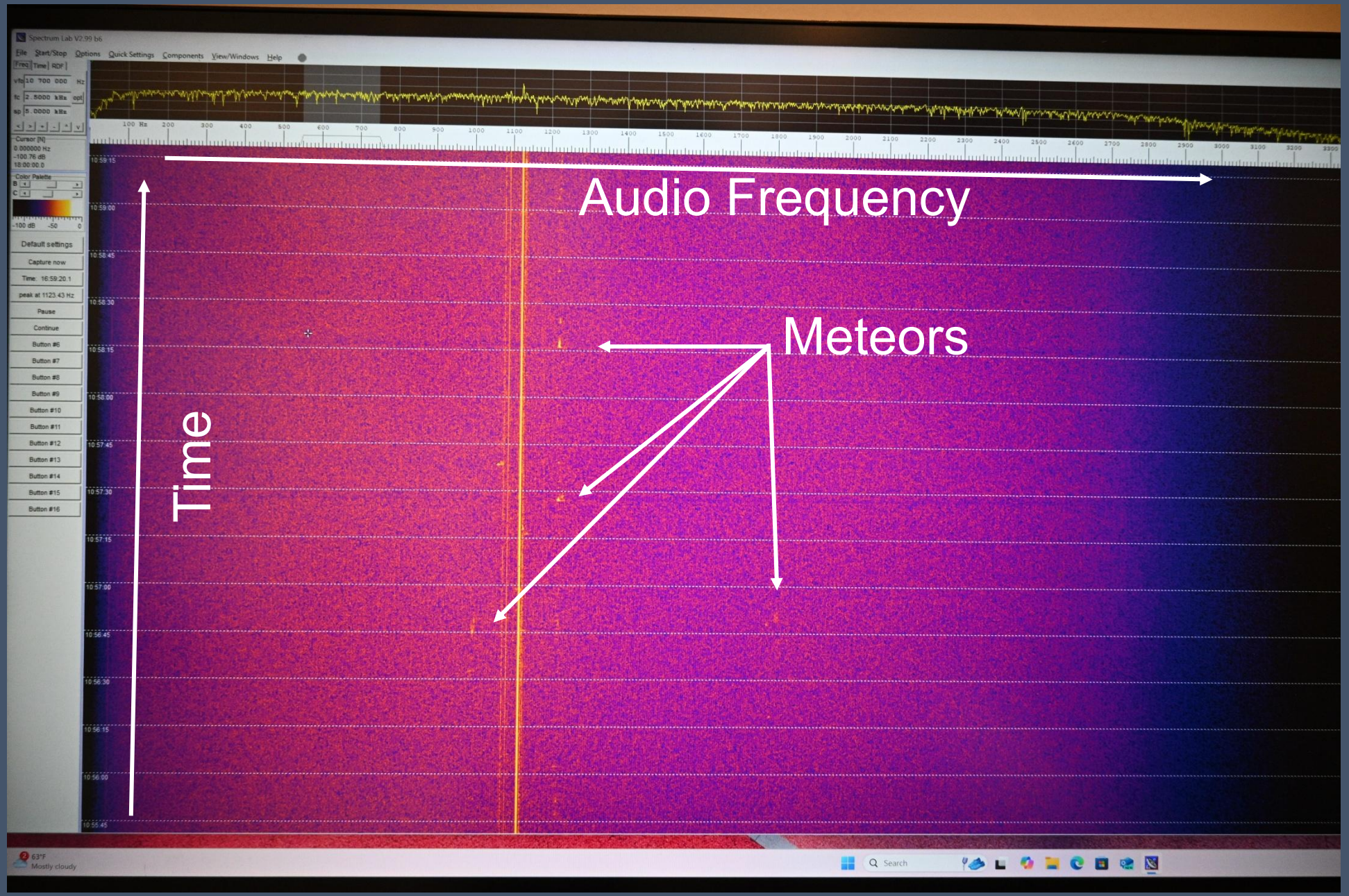
The pilot tone of a digital TV signal provides a continuous wave signal

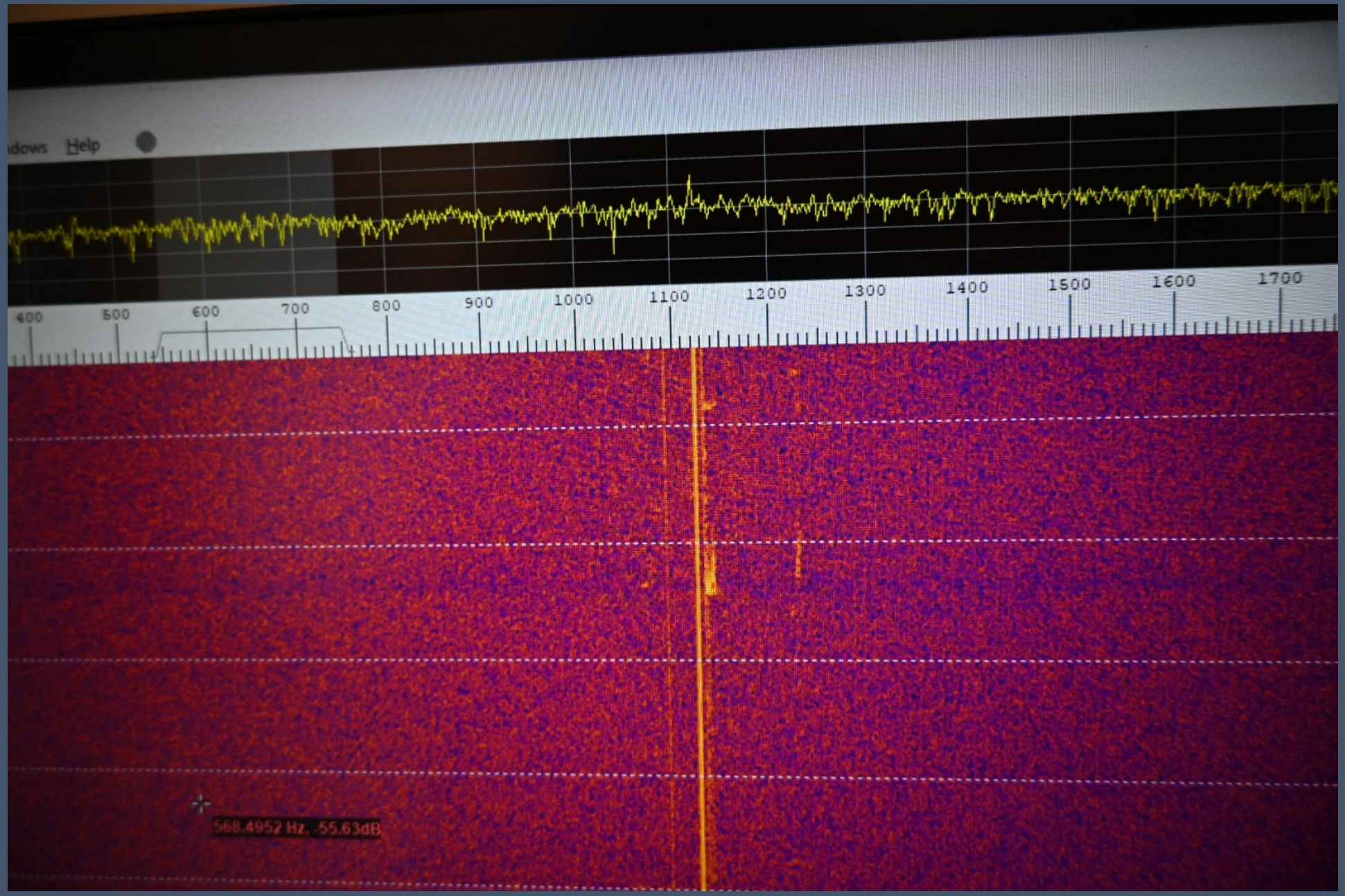


From Spectrum Tour: US Digital TV (551 MHz)
https://www.youtube.com/watch?v=OscnPDhxWEg

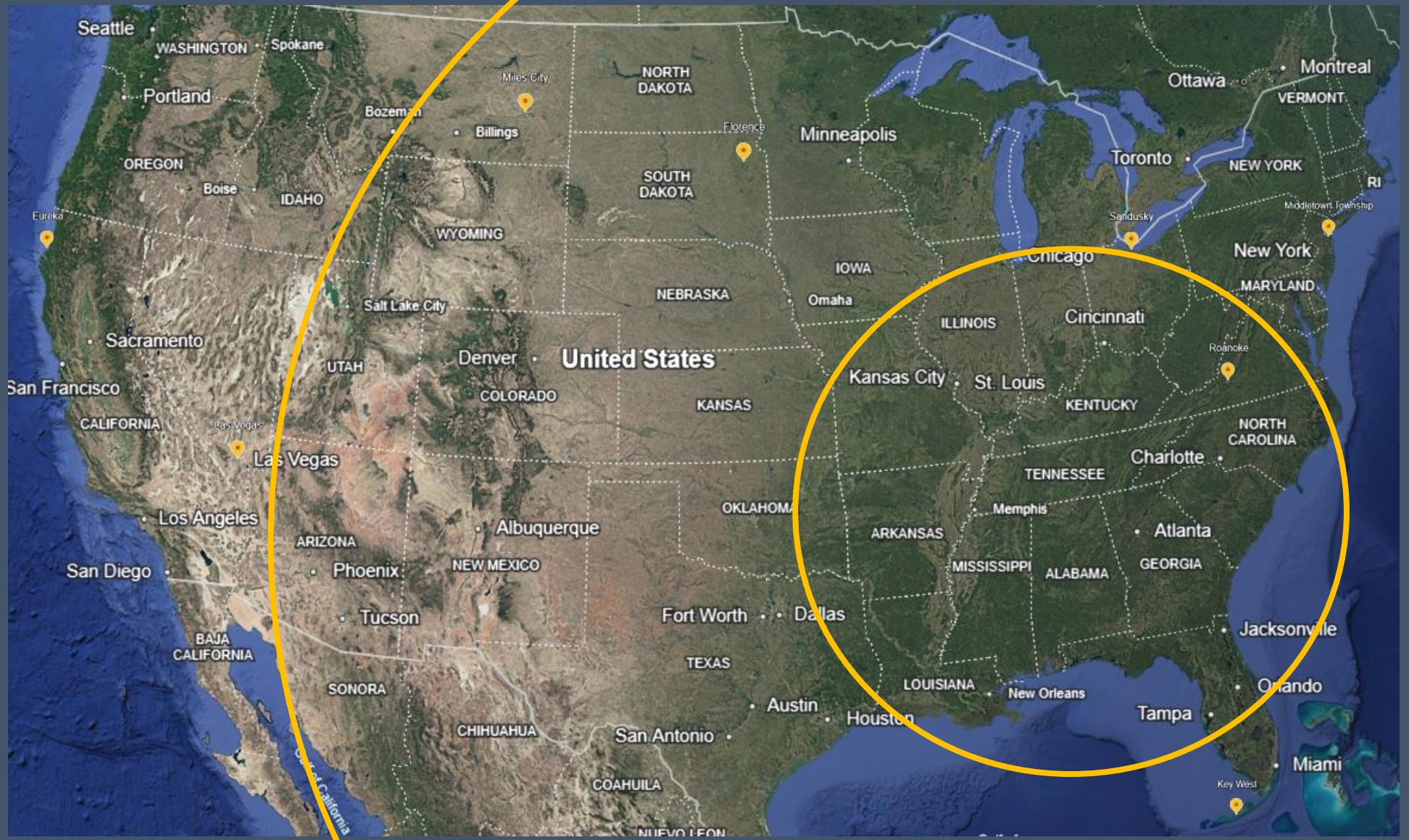
VBAS Meteor Radar Receiver System




Audio Frequency
Time
Meteors


dows Help
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
568.4952 Hz, -55.63dB

Digital TV Channel 3 Transmitters within range of Huntsville



Icom R-8500 receiver used at VBAS due to proximity of strong UHF TV stations

This can also be done with an inexpensive (~$40) RTL-SDR dongle

Download software such as SDRConsole to control the SDR and display the spectrum

Meteors occur in the E-region

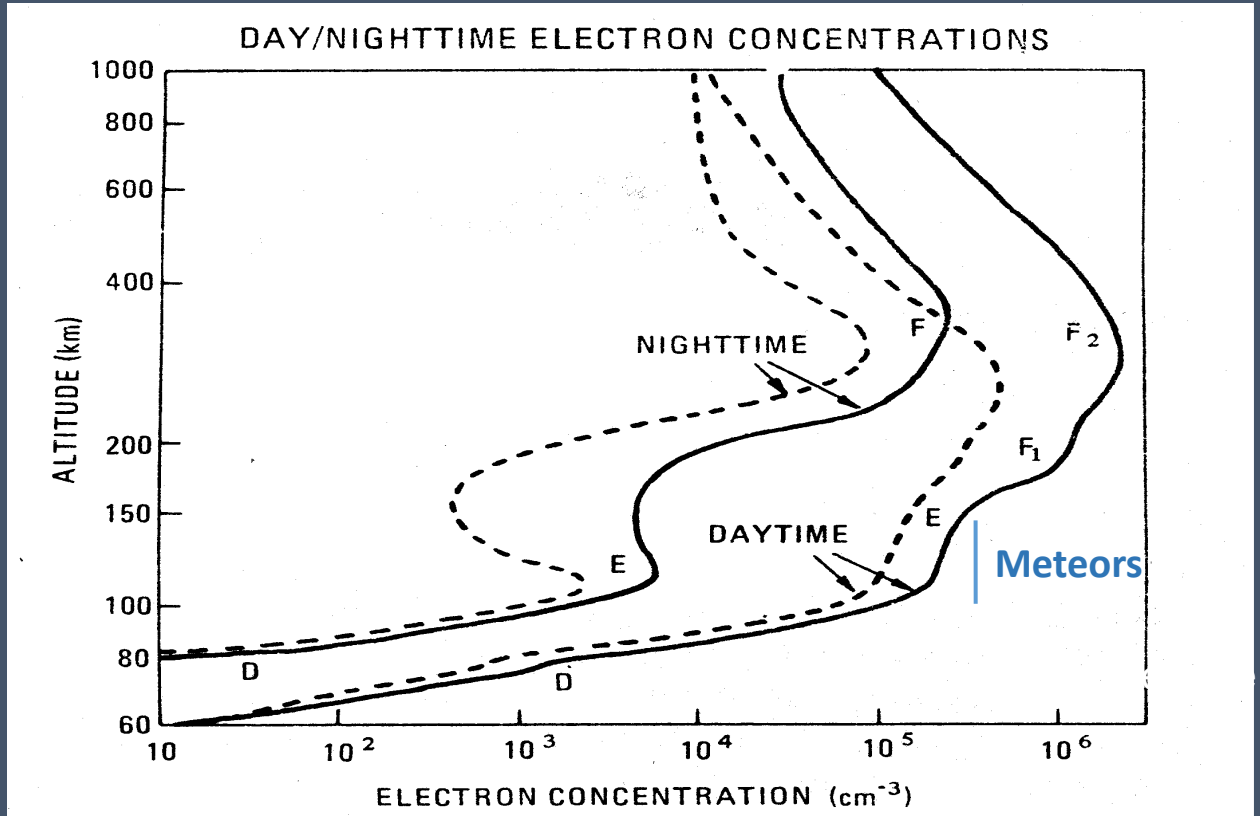
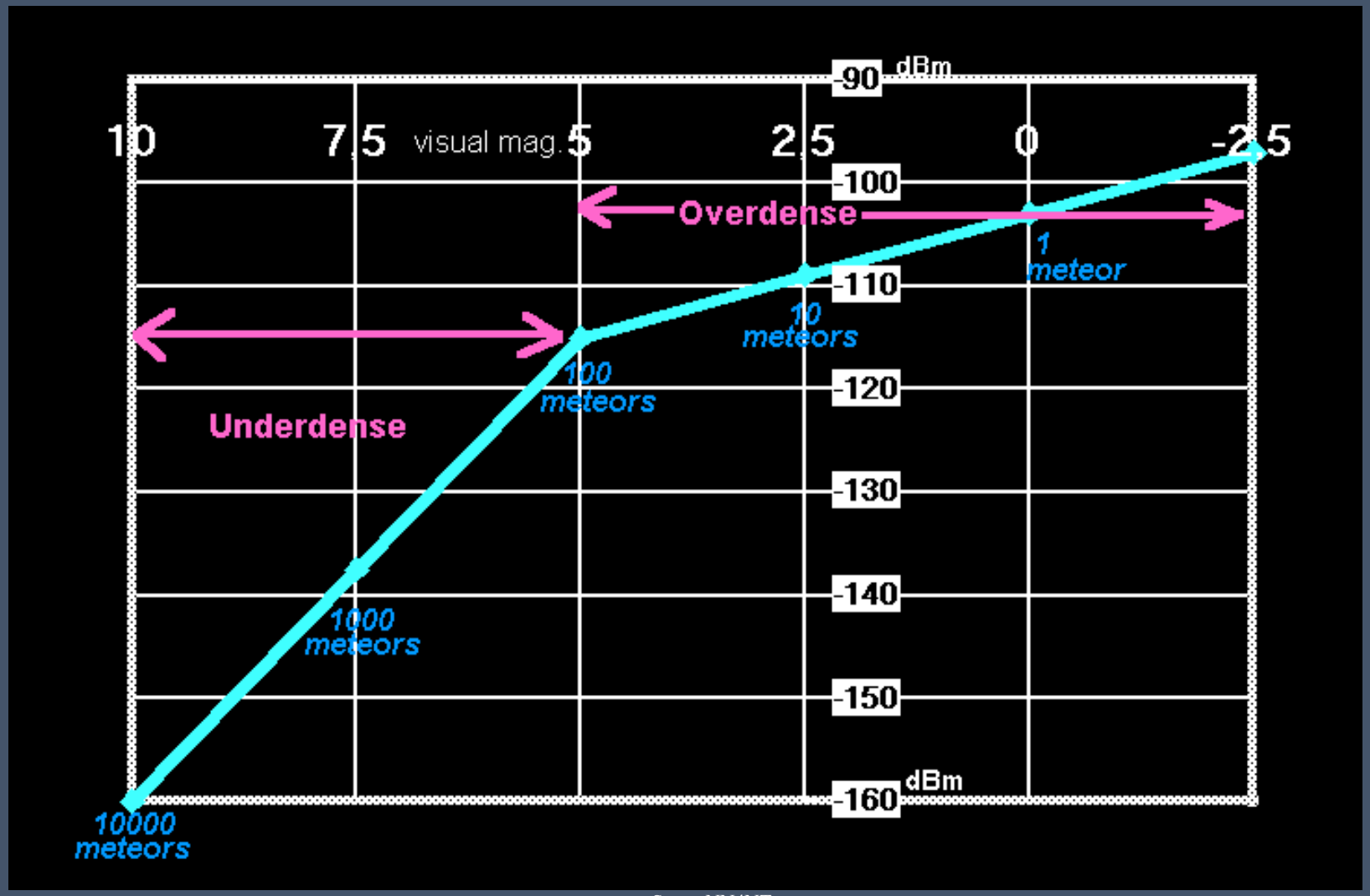


Figure 7.1 Typical midlatitude daytime and nighttime electron density profiles for sunspot maximum (solid lines) and minimum (dashed lines).

There are way more small meteoroids than large ones



Path Geometry – t_0 is point of closest approach to observer

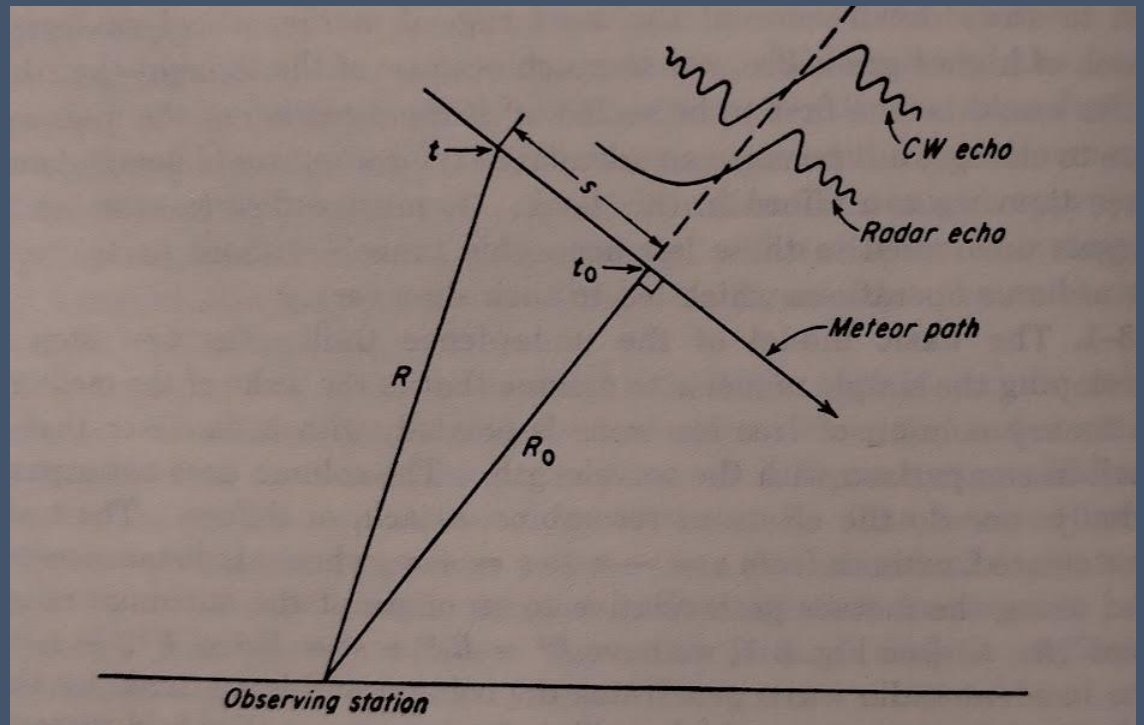
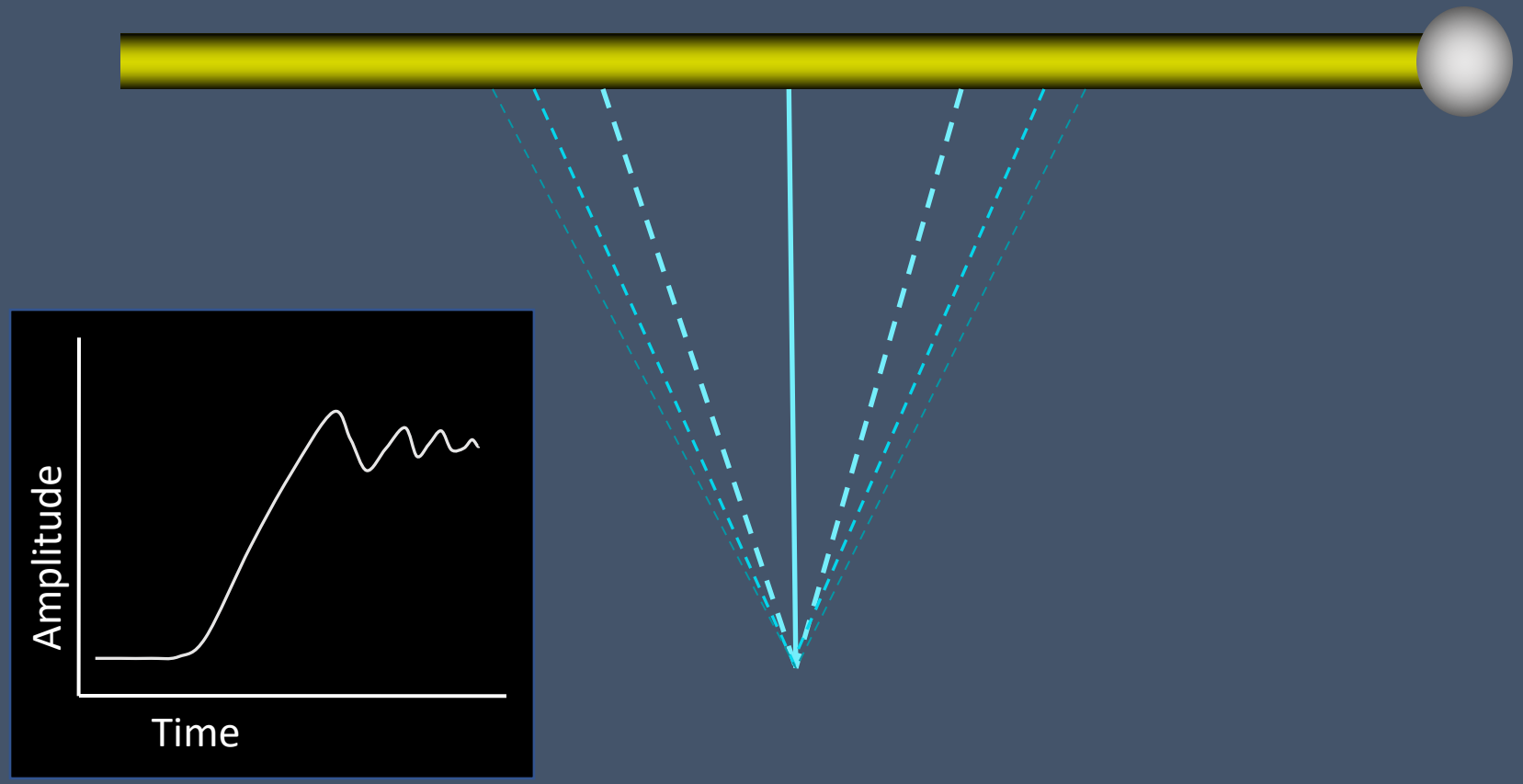


FIG. 8-1. The geometry of the meteor path relative to the observing station.

From “Meteor Science and Engineering”, D.W.R. McKinley

Fresnel scattering



Graphic from P. Brown, University of Western Ontario

Trail Expansion

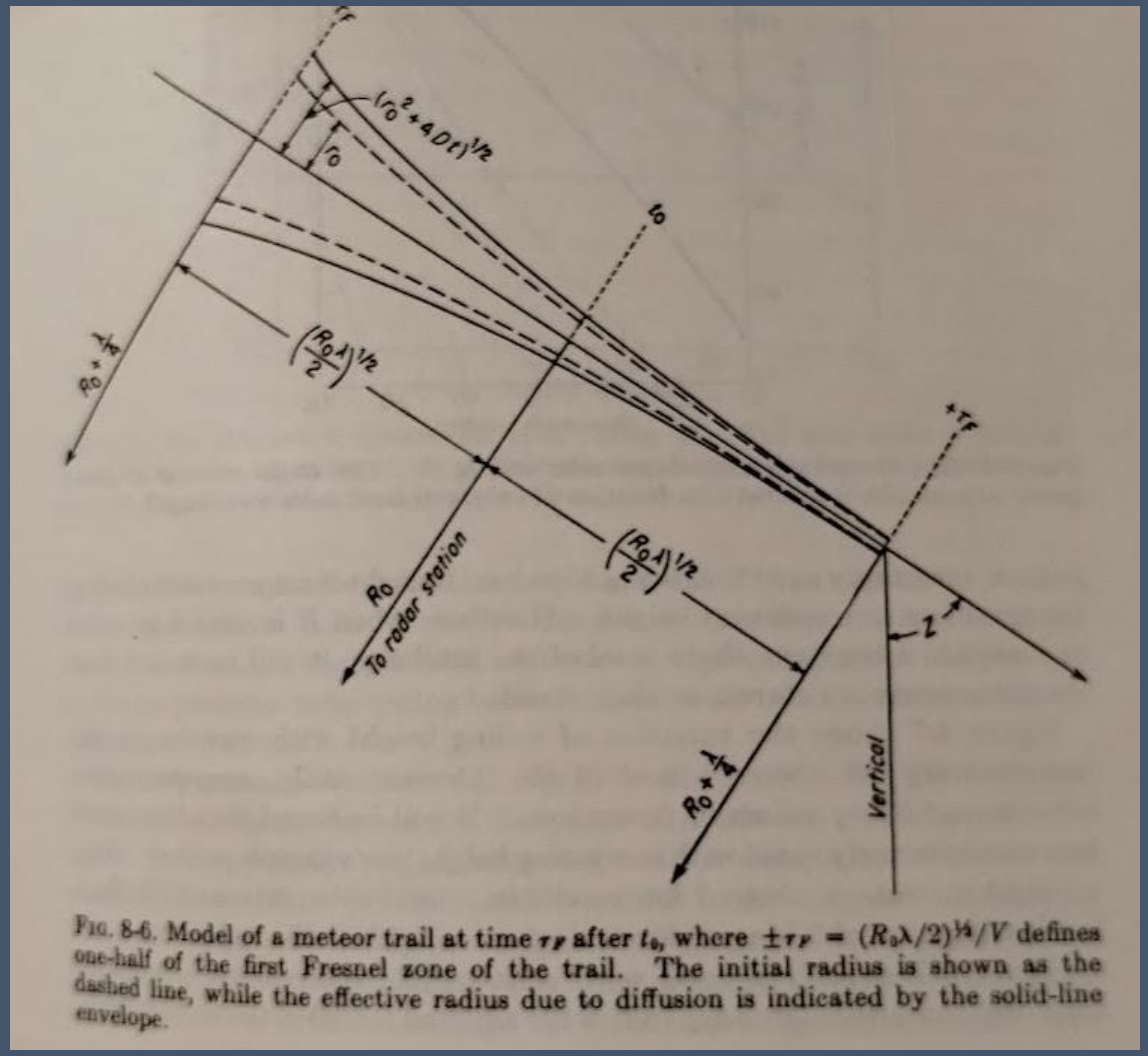


FIG. 8-6. Model of a meteor trail at time τ_f after t_0, where $\pm\tau_f = (R_0\lambda/2)^{1/4}/V$ defines one-half of the first Fresnel zone of the trail. The initial radius is shown as the dashed line, while the effective radius due to diffusion is indicated by the solid-line envelope.

From “Meteor Science and Engineering”, D.W.R. McKinley

Trail Cross Section

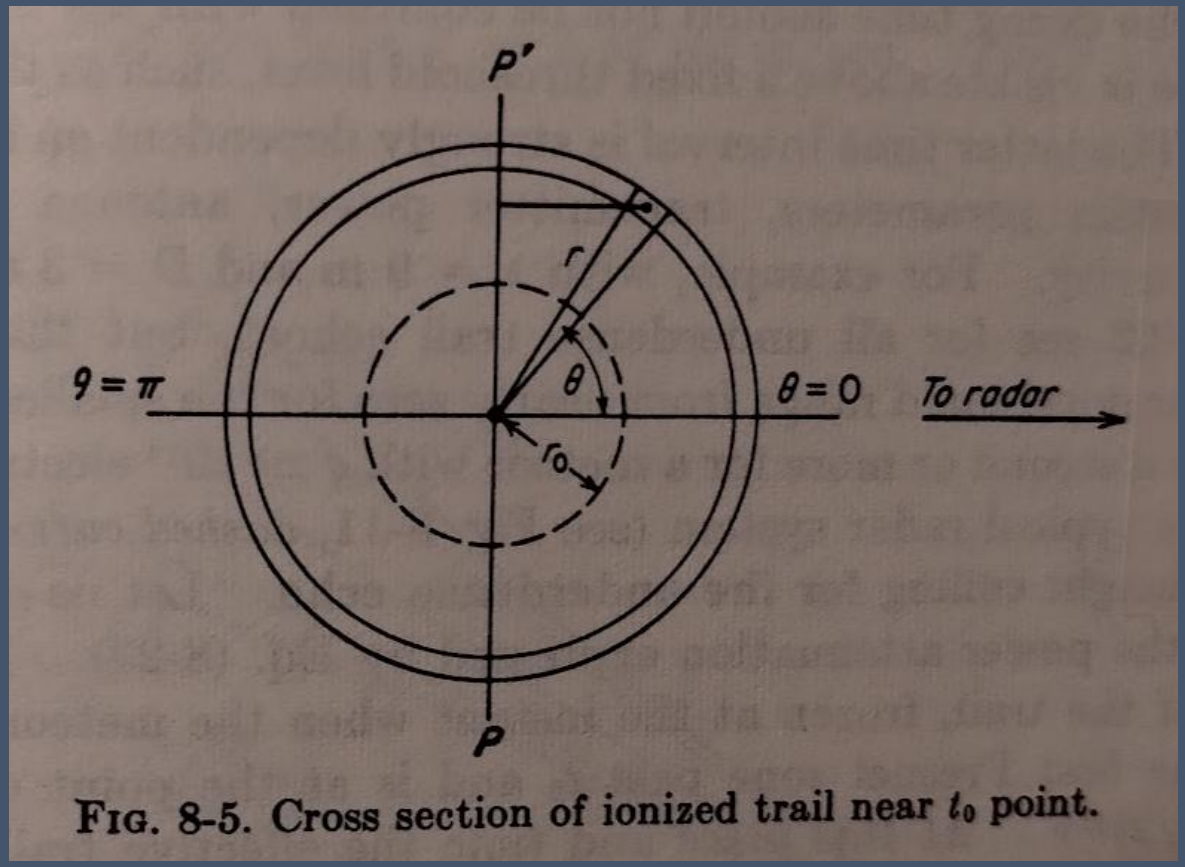
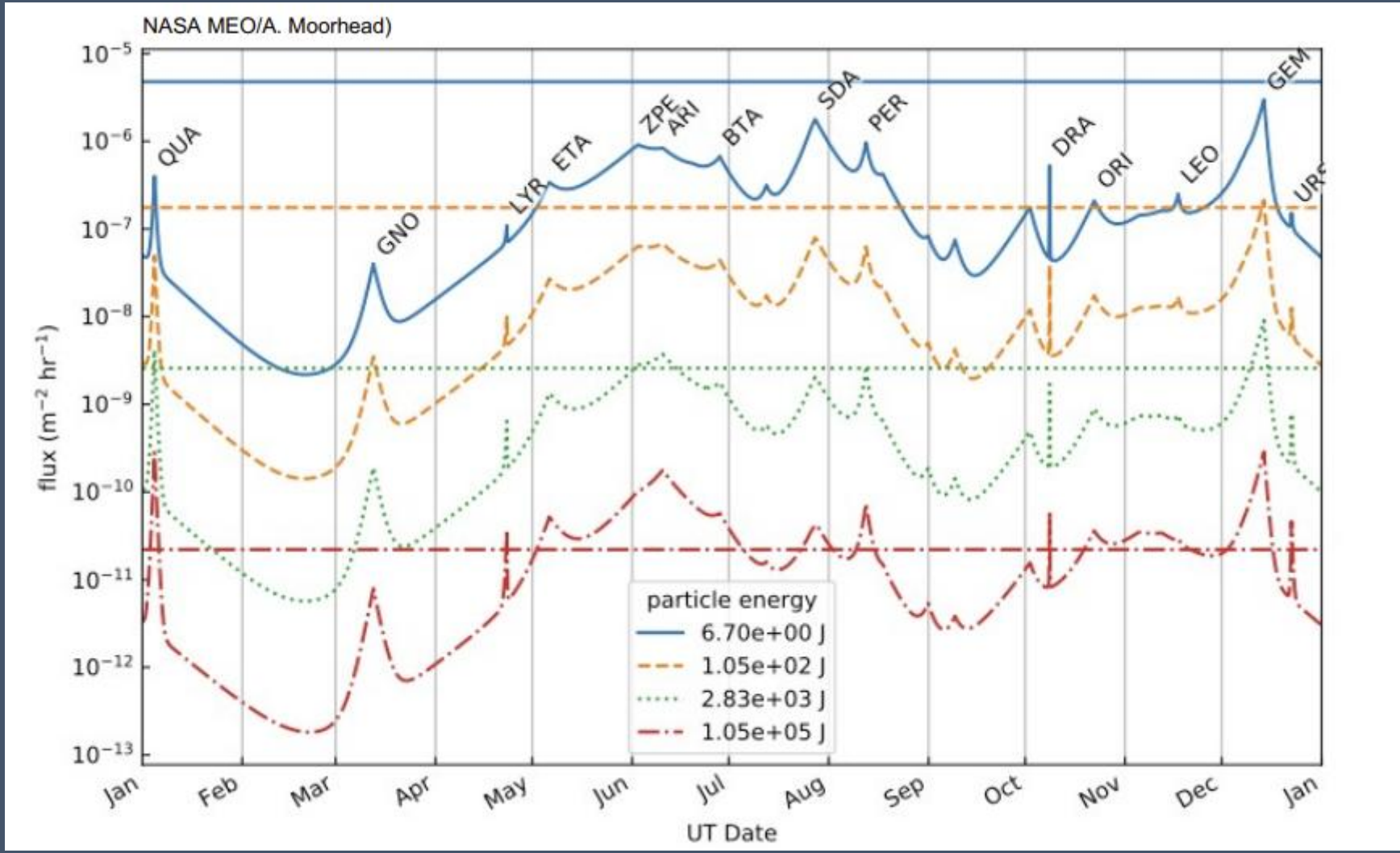


FIG. 8-5. Cross section of ionized trail near t_0 point.

From “Meteor Science and Engineering”, D.W.R. McKinley

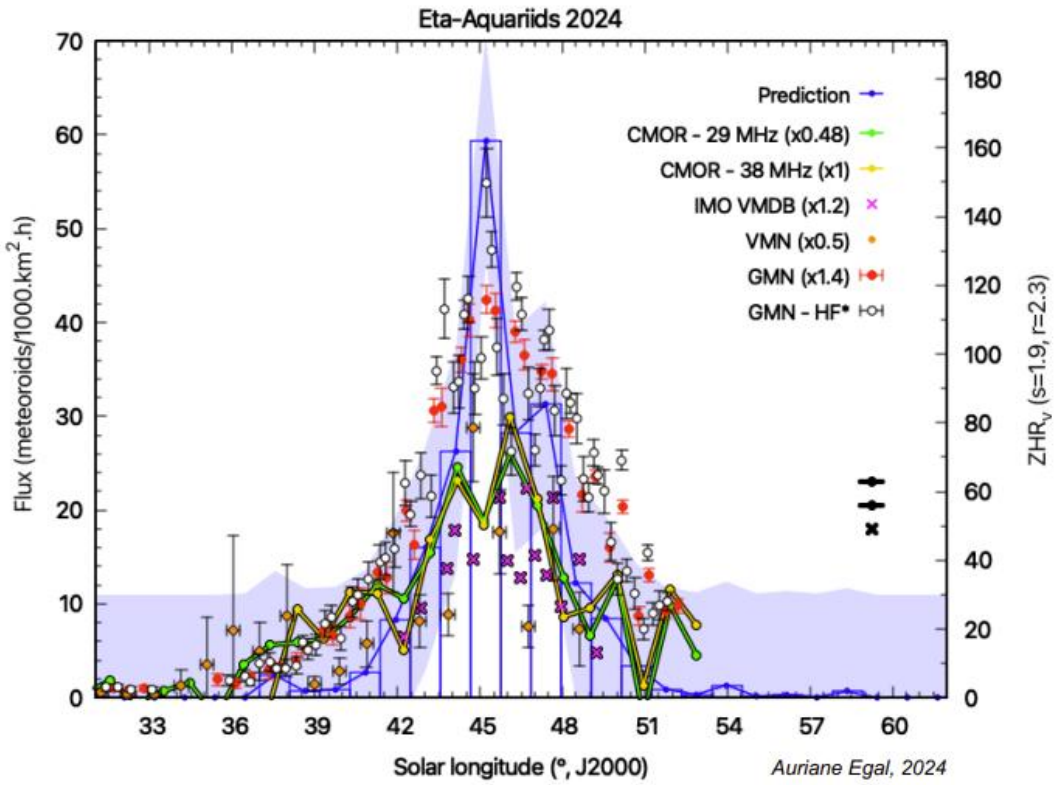
All Sky camera view of Perseid 12 Aug 2017

NASA Meteoroid Environment Office
All-sky camera network
Suggs NN4NT



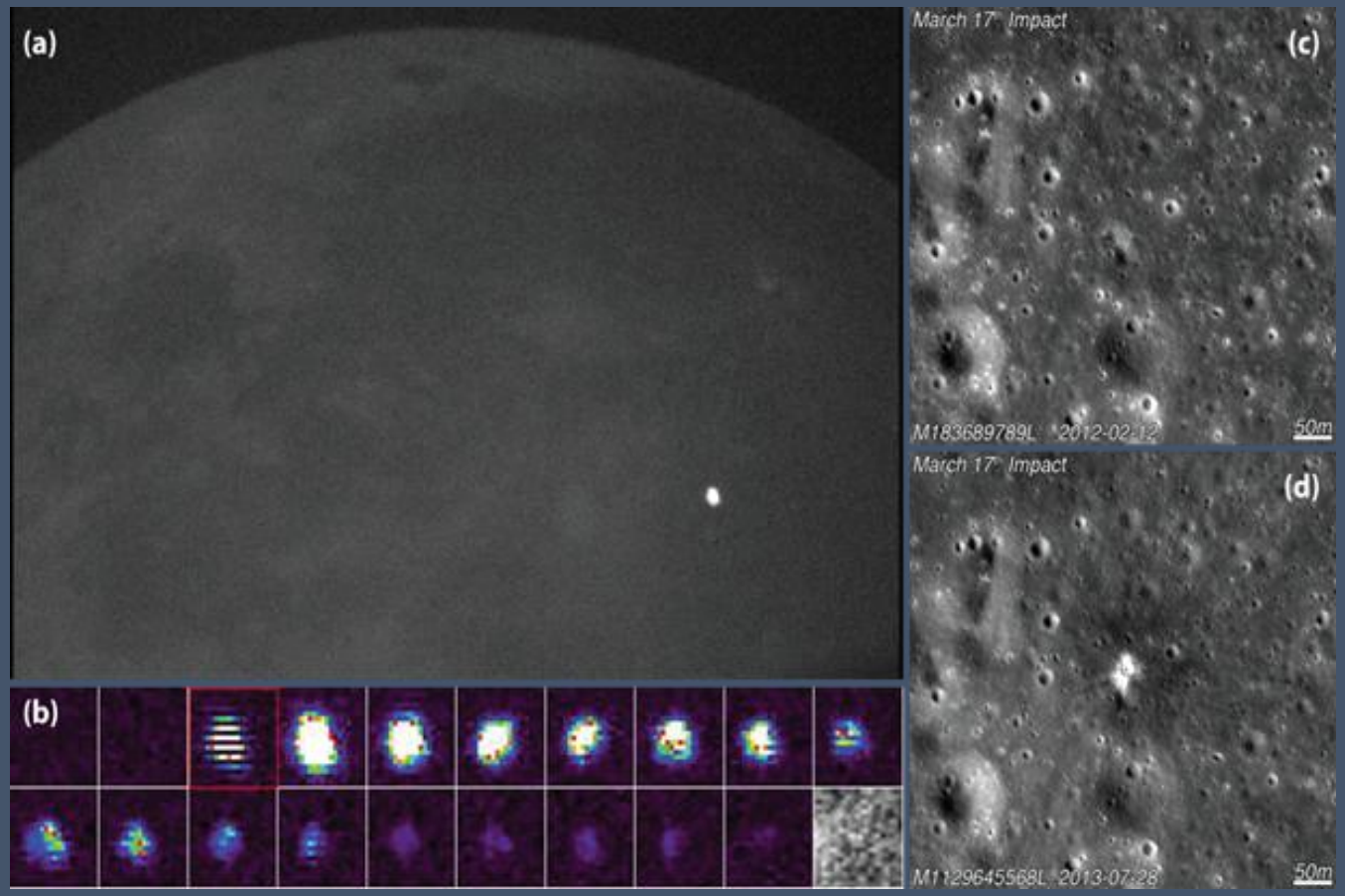
https://ntrs.nasa.gov/api/citations/20240010164/downloads/MEO_Workshop_2024Aug26_Bill.pdf

- Outburst forecast for May 5, 14 UTC (Solar Longitude 45.2)
- Peak ZHR of 130-160
- ~30% increase in meteoroid flux above sporadic levels



https://ntrs.nasa.gov/api/citations/20240010164/downloads/MEO_Workshop_2024Aug26_Bill.pdf

Meteoroid impact on the Moon
March 17, 2013 and resulting 18m diameter crater
(nothing to do with meteor scatter but cool anyway)



Impact flash from Suggs et al., Icarus, 2014
14 inch telescope at NASA MSFC, AL
https://www.nasa.gov/centers/marshall/news/lunar/index.html

LRO before and after images
Robinson et al., Icarus, 2015